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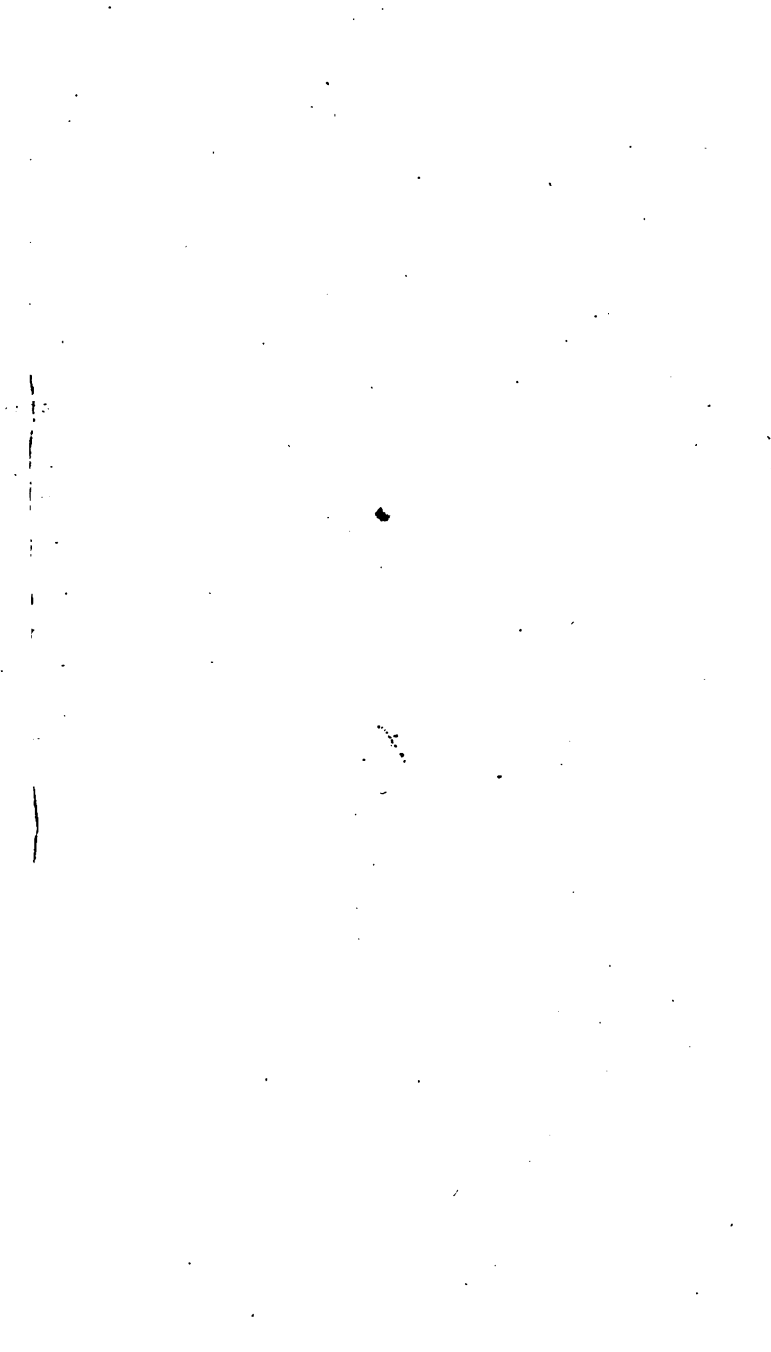
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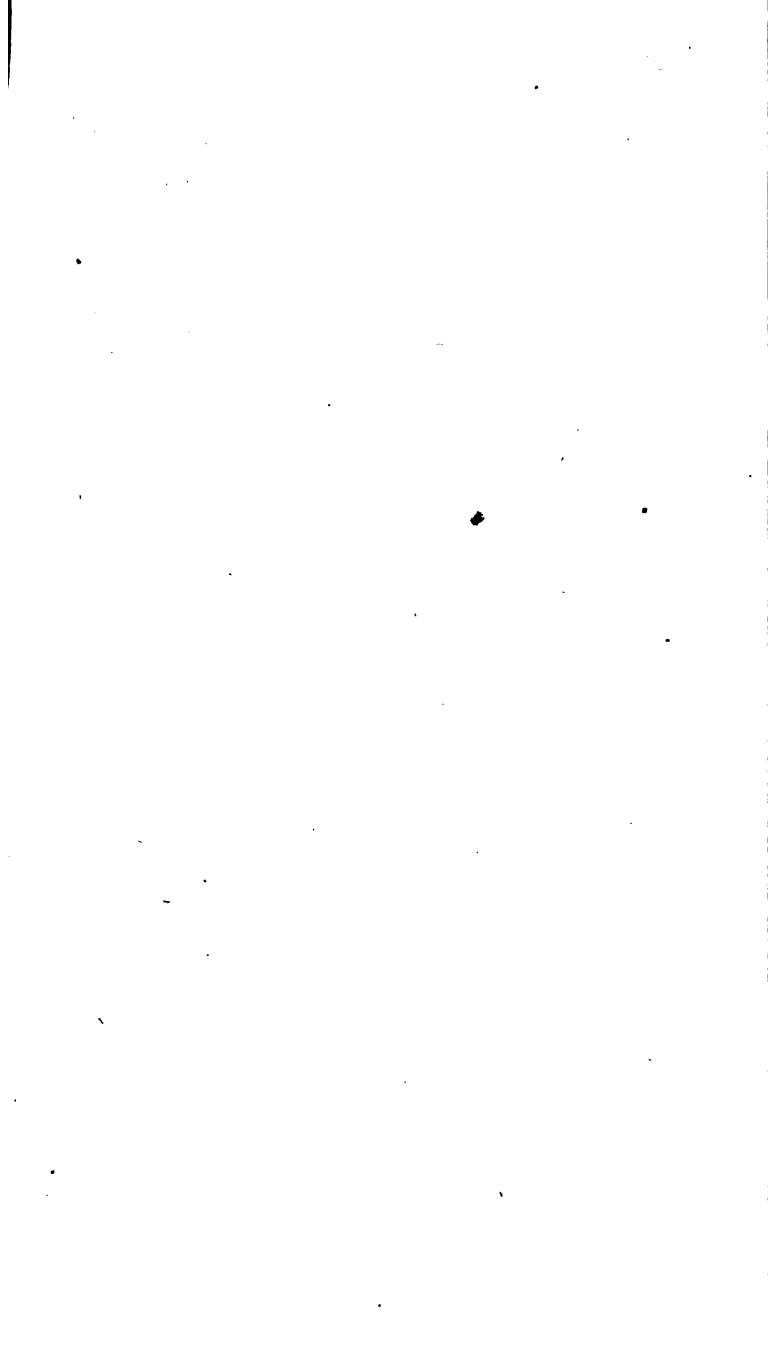
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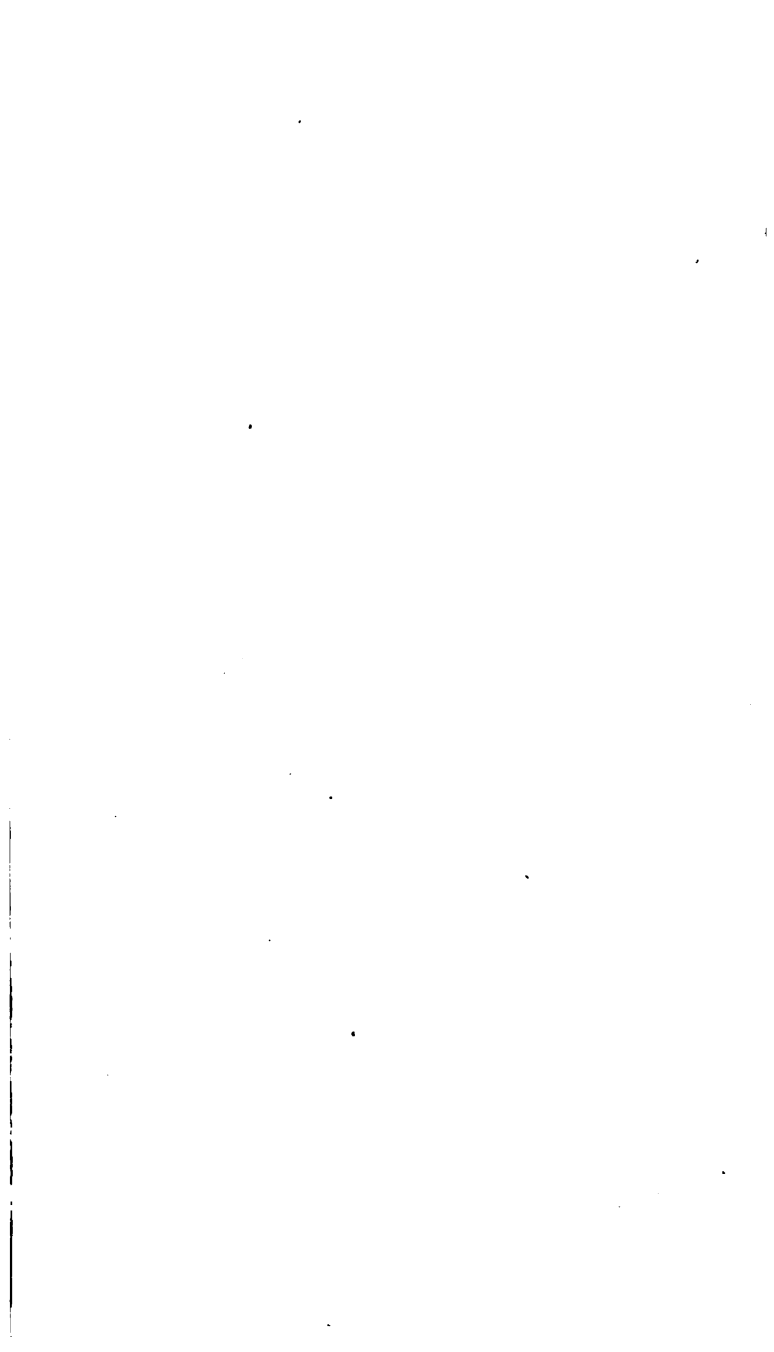
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THE  
RUDIMENTS  
OF  
HYDRAULIC ENGINEERING,

BY  
G. R. BURNELL, F.G.S.,  
CIVIL ENGINEER.

WITH ILLUSTRATIONS.

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PART I.

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## PREFACE.

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### HYDRAULIC ENGINEERING.

IN the first edition of the "Rudimentary Treatise on Civil Engineering," the plan upon which the whole subject was treated had been drawn up on such principles as to render necessary, in a manner, the discussion of many questions connected with the science of Hydraulic Engineering in the general body of the work. It would, perhaps, be difficult to define exactly the limit of demarcation between the duties of the civil and of the hydraulic engineer, if indeed any distinction between the two professions be recognised; so that even in reproducing the portion of the Treatise especially devoted to the latter division of the subject, in a separate form, much of the original confusion must still exist. An attempt has, however, been made to bring together in the following pages the consideration of the bulk of the subjects especially connected with building in water, or with the applications of that fluid; and, to some extent, to make this Rudimentary Treatise, as far as possible, complete in itself. But it must be observed that, firstly, the discussion of such subjects as those of bridge building would involve a

repetition of a large portion of the work already so well performed by Mr. Law; and, secondly, that the enquiry into the best methods of improving rivers, or of establishing canals, or into the laws of the resistance and movement of fluids, would lead to such an extension of this Treatise, as to render it advisable to depart, in some cases, even from this more recent programme. It is for these reasons, therefore, that the reader is still referred to Mr. Law's "Rudiments of Civil Engineering" for the technical details connected with bridge building; and that Mr. Weale has requested me to devote separate Treatises to some of the other branches of hydraulic engineering whose importance appeared to warrant the distinction; but, nevertheless, it has been my object to render the whole work as uniform and complete, and as free from repetitions, as possible.

It is far from being my intention to claim any merit on the score of the originality of the following pages. Indeed it is more than questionable, whether the author of a Rudimentary Treatise be entitled, under any circumstances, to venture upon the insertion, in such works, of opinions, or of doctrines, which are susceptible of dispute. It is his province to record the universally received theories on the subjects he treats, and he is thus debarred from the expression of opinions which may hereafter be proved to be incorrect. With such convictions then, I have carefully avoided the introduction of controverted doctrines, and have unhesitatingly resorted to the common fund of scientific knowledge to be found in the writings of the most

esteemed authors. Wherever it has been possible the names of those authors have been quoted; but no doubt many involuntary omissions have been made in this respect. The names of the authors consulted in the preparation of this work are, therefore, added in a special Appendix; and the more importance is to be attached to this list, inasmuch as it will (it is hoped) serve to guide the student in his future reading. There is great truth in the maxim, "*Scire ubi aliquid invenire possis, maxima pars scientiæ est;*" and it may be that the insertion of the Bibliography of Hydraulic Engineering would enable the reader to supply the deficiencies of this work itself. It happens that the majority of the best books on subjects connected with hydraulics generally are written in foreign languages; and perhaps it may be to this fact, that we owe the singular ignorance of educated Englishmen upon the subject. A series of translations, like Mr. Bennett's able translation of d'Aubuisson's *Hydraulique*, would be of great value, and might induce even our legislators to pause before they meddled with subjects they are apparently so little able to comprehend. In the meantime a mere list of these authors will be of use.

That, in fact, our legislators are often misled in these matters, must be evident to any one who recalls the history of the "Sanitary Movement," as it is called, within the last few years. It would be difficult to say how this unfortunate tendency is to be effectually combated; but, at any rate, it is the duty even of the writer of a Rudimentary Treatise, to call attention to



the most flagrant of the mistaken theories which prevail in high, or authoritative, quarters. In the sections of the following little work devoted to the consideration of town sewerage, and town water supply, an attempt has therefore been made to divert public attention from the incorrect doctrines lately promulgated "by authority" on such subjects, and to direct that attention to the writings of the men who really knew something of the laws (both natural and municipal) which affect those branches of hydraulic engineering. Of course it would be impossible to exhaust such investigations in a merely preliminary treatise; and for this reason again, it has become important to place before the public such indications of the best sources of information, as may enable it to complete what may herein be deficient. The necessity which unfortunately exists for attacking some of the doctrines recently propounded by the very branches of administration which profess to "guide public opinion," may, however, give to some portions of the following work somewhat of a controversial nature. This is much to be regretted; and, as far as possible, I have sought to avoid such discussions, and have only introduced them when it appeared to be absolutely necessary so to do, in order to resist the diffusion of mischievous error. Singularly enough one of the members of a recent ministry was actively concerned in the promulgation, in a neighbouring country, of some of the absurd nonsense with respect to these subjects of sewerage and water supply which has cost us so very dear. It behoves all engineers, then, to record their protest against the

theories and practices so recommended, and to save others, if possible, from the bitter disappointment which they would infallibly encounter if they followed such blind guides. Besides this cosmopolitan motive for alluding to the errors of our rulers, it is now, more than ever, important to induce the public to revert to sound doctrines on many points connected with the application of the physical sciences; for the evil consequences of the mistaken principles lately applied to town sewerage especially, are beginning to produce fearful results. The state of the Thames and of many of our great rivers, indeed, is such as to inspire well-founded apprehension, and also, I fondly hope, an earnest desire on the part of the public to hear any conscientious opinion as to the measures requisite, either for the prevention, or for the remedy of evils so imminent, and so enormous.

In this edition of the *Rudiments of Hydraulic Engineering*, an attempt has been made to embody our present knowledge of the Chemistry of Building materials with the other portions of the theory of that branch of the profession. This section is, in fact, little else than a condensation of a paper read by myself at the Institute of British Architects, and of an article on Atmospheric influence inserted in the "Dictionary of technical terms," published by the Architectural Publications Society. It is avowedly incomplete; because hitherto very little attention has been devoted to the subject, and there is little satisfactory knowledge thereon to be discovered in the best treatises on Engineering. The insertion of this

section may therefore, it is hoped, call the attention of more able enquirers to an investigation of such vital importance. Of late years also the operations of both English and Foreign well sinkers have thrown so much light on the subject of the internal constitution of the Globe as to render it desirable to extend the short notice originally given upon Artesian wells; and the brilliant success of the operations of the Belgian Government in the irrigation of the Campine, and of the late East India Company in its dominions, has appeared a sufficient justification for the references to them. With all possible care and attention, however, a work of such a wide range as a Rudimentary Treatise on Hydraulic Engineering must ever be incomplete; and, at best, its only merits must consist in the earnest endeavour of its writer to place before the student, in an intelligible form, the truest statement of the universally admitted laws affecting that noble profession.

# HYDRAULIC ENGINEERING.

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## CHAPTER I.

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1. THE details of Engineering practice which are connected either with the application of water, or with the resistance to its effects, have usually been considered to form part of an important subdivision of the general body of the sciences applied to that profession; and they have been distinguished by the specific name of Hydraulic Engineering. Very strong objections might be raised to this name, for its derivation would certainly indicate that it cannot logically be applied to the bulk of the subjects which it has been made to express; but the use of the word, in the sense referred to, is now so general that there would be danger in attempting to alter it, or to substitute another in its stead. In the following treatise, therefore, the inquiry into the principles of Hydraulic Engineering will be considered to include the discussion of the various questions connected with building in water for whatever purpose, and also of those connected with the use of water commercially, agriculturally, or for municipal requirements. It will thus be necessary to examine, with more or less detail, the principles to be observed in the construction of bridges, canals, docks, harbours, lighthouses, sea walls, &c.; in the execution of works of drainage, warping, irrigation, sewerage,

water supply, river improvement, reclaiming of land, &c.; or, in fact, to investigate the various circumstances under which it may be necessary to resist, to control, or to distribute water.

2. The hydraulic engineer, as the term is above explained, is thus called upon to ascertain the mechanical laws, and the chemical or physical properties of water, and of the various materials exposed to its action. Before, therefore, directing attention to the practical details of the various descriptions of work named above, it is expedient to state briefly the laws and properties thus referred to, or to give a slight sketch of the sciences of hydrostatics, hydraulics, pneumatics, and of some parts of that of applied chemistry.

#### HYDROSTATICS.

3. Under the generic name of **HYDRODYNAMICS** are included, firstly, **HYDROSTATICS**, or the laws of the pressure of water when at rest; and secondly, **HYDRAULICS**, or the laws of water in movement. Water is considered, in the reasoning usually adopted upon these subjects, to be an incompressible fluid, and its molecules are assumed to exist in a state of cohesion so slight that they are susceptible of being moved in any direction (unless restrained by external objects), without experiencing any sensible resistance. By the addition, or subtraction, of heat water changes its physical condition; becoming, in the former case, an elastic and compressible vapour; and, in the latter, a solid body, subject to all the ordinary laws of such bodies. Hydraulic engineering is principally confined to the operations in which water acts as an incompressible fluid, although occasionally it is essential to take into account the various effects produced by, or attending, its changes of state.

4. Perfectly pure water at its maximum density (which takes place when the temperature is  $39.2^{\circ}$  Fahrenheit), weighs 62 lbs. 5 oz. per cubic foot; and its specific gravity is usually considered to be represented by that quantity. Above  $39.2^{\circ}$  water gradually and slowly diminishes in its specific gravity with great regularity; and a similar diminution, but of a more irregular character, takes place when the temperature falls below the point so named. If the specific gravity of water-at  $39.2^{\circ}$  be taken as unity, that of water at  $122^{\circ}$  will be 0.98758, and that of water at  $212^{\circ}$  will be 0.95670; whilst the specific gravity of ice itself does not exceed 0.930. It is in consequence of this decrease in the specific gravity of ice, below that of water, that the former rises to the surface, and thus to some extent protects the water beneath it from frost.

5. The salts which are contained in water affect its specific gravity to a trifling extent in ordinary spring or river waters, and to rather a more appreciable extent in those of the sea. Taking distilled water as the type, filtered river water, when free from mechanical impurities, does not differ from it in weight to the extent of more than from 1 to 2 parts in 10,000. Some accurate observations made upon the waters of the Garonne showed that its waters had a specific gravity of 1.00014; and similar observations upon the waters of the Seine gave as nearly as possible the same results. Rivers, such as the Nile during the floods, or the Ganges when at the full, bring down remarkably large quantities of alluvial matter; and indeed it would appear, from the observations of Mr. Piddington, that the mean specific gravity of the latter, as compared to that of pure distilled water, is not less than 1.00153. Sea water is, however, still heavier; its specific gravity is at times 1.028, and a cubic foot weighs 64 lbs.  $2\frac{1}{2}$  oz.

6. In stating above that water is incompressible, it must be understood that the term is only applied in a practical sense. Water is in fact compressible, but so very slightly, that the diminution under the pressure of one atmosphere is only about  $0.000046$  of its original volume. It hardly ever happens that the operations of hydraulic engineers are carried on under circumstances to render it necessary to notice this variation in the density of water; and, indeed, insomuch as water does not vary in its specific gravity at ordinary temperatures, or under ordinary mechanical conditions, within a wider range than  $0.9984$  or  $0.999$  of its normal gravity taken as unity, there can be no reason for considering it otherwise than as a fluid of a uniform character possessing the following mechanical properties. 1, It is incompressible; 2, its molecules are susceptible of free motion in every direction; 3, it communicates equally throughout its mass, the pressure exercised upon any particular point; 4, in any definite liquid mass any molecule supports in every direction a pressure equal to the weight of a vertical column of similar molecules, starting from it, and continuing to the surface of the liquid. From the latter property of incompressible fluids many important laws of hydrostatics are derived; these are,

*a.* Every layer, or horizontal film of a homogeneous liquid mass, supports an equal pressure on every part of its surface;

*b.* The sum of the pressures supported by any horizontal film is equal to the weight of the liquid cylinder or prism, whose base is the surface of the layer, and whose height is the distance from this layer to the upper surface of the fluid mass;

*c.* The pressure exercised upon any portion of a containing surface, whether horizontal, vertical, or

inclined, is perpendicular to that surface; for the pressure must be resisted by the containing body, and the surface of the latter can only resist perpendicularly to its own direction; the pressure thus exercised is equal to the weight of a liquid column having for its base the portion of the surface under consideration, and for its height the distance from that portion to the surface of the fluid;

*d.* The pressures being equal upon all the points of the lower horizontal surface of a vessel containing a fluid, the total pressure supported by that surface is equal to that of the column whose base is the surface itself, and whose height is the distance between it and the upper surface of the fluid: so that this pressure would remain the same whatever were the form of the vessel, provided that the area of the bottom, and the height of the liquid did not vary.

7. The above laws furnish the means for calculating the resistances which vases, or containing substances must offer to the pressure exercised upon them by a fluid. Thus: when a vase with a circular horizontal section, small in proportion to the height, contains water, each horizontal ring is pressed, on all its points, by the column of water above it. Now, as in the case when all the points of a circle are equally pressed in an outward direction, the effects of this pressure to force out the containing sides of the circle are proportional to the intensity of the force acting upon each point, and to the radius of the circle itself, it follows that the effort of a fluid to burst a circular vase is proportional to the distance of the ring under consideration from the surface, and to the radius of the vase. Evidently, under these circumstances, the thickness of the containing sides of the supposed cylindrical vase ought to be increased in proportion to the depth



of the fluid, if it were only desired to make them barely in excess of the theoretical dimensions. When the shape of the vase, instead of being cylindrical, is that of a cone with the larger diameter downward, the forces which tend to produce rupture, increase not only with the depth but also with the diameter at the level considered; and in this case the thickness of the containing sides would require to be increased in the lower portions over that which would have been necessary had the vessel been circular, and of the small upper diameter, instead of being conical. If, therefore, in a large vase of this description, a uniform thickness be given which is sufficient to resist the effort exercised upon the bottom, it will be in excess of the thickness absolutely required at the top.

8. In fact, the tangential force exercised by a fluid upon the sides of a vase may be represented algebraically by the simple expression  $R h$ ; in which  $R$ =the radius, and  $h$ =the vertical pressure supported by the surface of the ring. The thickness necessary to resist this force must, therefore, be such as to present a resistance greater than the effort  $R h$ , under any circumstances; whether those circumstances arise from an accidental increase of pressure, or from a diminution of the original resistance of the materials of the vase, by oxidation or by any other cause.

9. It is often necessary to ascertain, not only the total value of the pressure exercised against any definite portion of the surface of a vessel containing a fluid, but also the point of application of the resultant of the various pressures to which that surface may be exposed; for this would evidently be the point to which it would be desirable to apply a resistance which should be able to counteract the first-named forces. This point is known by the term of the "centre of pressure."

10. Now, it must be evident that if the pressures exercised upon the different portions of the surface were co-equal, the centre of pressure would coincide with the centre of gravity of the surface; but as the pressures vary with the distance from the surface of the fluid, the centre of pressure is always below the centre of gravity. It is found, in fact, that the centre of pressure against a rectangular plane surface, whose upper side coincides with the surface of the water, exists upon the line joining the horizontal surfaces, at a distance of two-thirds of its height from the top; or calling  $x$  the centre of pressure,  $l$  the height of the rectangle measured on the line joining the middle points of its horizontal bases,  $x = \frac{2}{3} l$ . The centre of pressure of a triangular surface, whose base is horizontal and upon the upper water line, is in the middle of the line joining the summit with the horizontal base; or,  $x = \frac{l}{2}$ . The centre of pressure of a triangle whose summit is at the water line, and whose base is horizontal and at the lower level, is on the line joining the summit to the middle of the base, and at three-fourths of the distance from that summit; or  $x = \frac{3l}{4}$ .

11. Should the surface of the bottom of the containing vessel not be horizontal, as it has hitherto been supposed to be, the pressure exercised upon it will be ascertained by multiplying the area into the depth of the centre of gravity of the irregular surface from the upper surface of the fluid. It must be borne in mind, in all calculations of this description, that whatever be the pressure upon the sides of any vessel, ascertained by the laws given above, the pressure upon the bottom is equal to the weight of the whole fluid acting upon it vertically. In close vases, also, if any pressure be applied

to the surface of the fluid they may contain, every proportion of the sides and bottom would be affected by it. It is of the utmost importance that attention should be paid to these laws in calculating the dimensions of constructions intended to hold or to resist the action of large bodies of water, such as reservoirs, sluices, &c. ; and it may be convenient to remember, that the pressure of fresh water is nearly 13 lbs. upon every square inch of horizontal surface at the depth of 30 feet, and so in proportion for greater or less depths of water.

12. If still water be contained in vessels communicating freely with one another by means of tubes or passages of considerable dimensions, evidently the equilibrium of pressure cannot exist unless the water stand at the same level in all of them ; or, in other words, the pressure arising from the weight of a fluid being proportional to its height, and being equally transmitted in every direction, the surface must always be at the same level in all vases communicating with one another. It is upon this law of the equilibrium of liquids in communicating vessels that the details of works for the connection of reservoirs are calculated.

13. But the law in question only holds good when the communication is of considerable sectional area, and the water is retained in the supposed vessels : when the passage is very small, the equilibrium becomes affected by a new power, known by the name of "the capillary action." This action may, indeed, be observed whenever a body is immersed in water, for the latter either rises or falls round it ; and, according as the body may be raised or depressed, the water itself assumes a concave or convex form. There are few substances in nature which do not possess the power of producing this phenomenon : polished steel is however one of the most remarkable exceptions,

and when a bar of that metal is plunged into water, the fluid retains its level at the point of contact with the surface of the steel. But, of course, the effects of capillary action are only feebly displayed when the exposed surface of the fluid is comparatively large; indeed, the very term *capillary action* (or that variation of the ordinary laws of Hydrostatics observable in small tubes whose diameters do not much exceed the dimensions of a hair), implies that it takes effect principally in small tubes.

14. In fact, the energy of the capillary action depends very much upon the form, distance apart, and disposition of the sides of the tubes which excite it. In minute cylindrical tubes, for instance, it is greater than it is in prismatic tubes; and in both descriptions it is greater than when the action takes effect between parallel plates. The elevation, or depression, in cylindrical tubes is in the inverse ratio to their diameter; in prismatic tubes it is in the inverse ratio of the wet contour of the horizontal section; whilst in the case of parallel plates, it is in the inverse ratio of their distance asunder. The surface of the fluid between the plates is perceptibly a demi-cylinder, with a semicircular base, whose axis is horizontal; in a cylindrical tube the surface is that of a demi-sphere, whose diameter is equal to that of the tube itself.

15. Minute as the effects of capillary action may appear to be to a casual observer, they are of the greatest importance in many branches of physical science, and even practically they merit greater attention than they usually receive from engineers, or architects. Thus, for instance, the capillary actions which take place in building materials have a very perceptible influence upon the durability of the latter, and these may be observed to disintegrate the most rapidly at

the limits of the capillary actions. In the cases of sea, or river, walls backed up with earth, the capillarity of the earth causes it to take up water, and thus to become increased in weight; so important, indeed, does this consideration become, when the walls in question are exposed to the influence of tides, that it becomes necessary to allow for the thrust of the earthwork, on the supposition of its being a semi-fluid denser than the earth itself in its dry, or normal, condition. Many failures of wharf, or of retaining, walls have occurred from the neglect of this apparently self-evident law.

16. If a body be immersed in a fluid it is necessary, in order that it may remain in equilibrium, that—1, its weight should be equal to that of the fluid displaced; 2, the centre of gravity of the body and of the displaced fluid should be upon the same vertical line; and 3, the centre of gravity of the body should be as low as possible. The two first conditions evidently result from the fact that the weights of the body and of the fluid act as parallel forces, which can only destroy one another when they are equal and are directed in the same line; the influence of the last condition of stability arises from the law by which the centre of gravity of any body has an invariable tendency to assume the lowest position.

17. When, however, the body, instead of being entirely immersed, floats upon the surface of the fluid, the conditions of equilibrium are virtually the same as they are in the latter case; for the body tends to sink by its own weight, and to rise by the pressure which the fluid exercises upon the portion of its surface submerged—this pressure being evidently equal to the weight of the fluid displaced, and considered to be applied at its centre of gravity. It follows from this, that in order that a body may float upon the surface of

a fluid, its weight must be less than the weight of an equal volume of the latter. Should the body and the fluid actually be in a state of equilibrium, the weight of the fluid displaced must therefore be equal to the total weight of the body; and the centres of gravity of both the liquid displaced and of the body displacing it, must be in the same vertical line. The equilibrium will only be stable when the centre of gravity of the body is lower than that of the fluid displaced by it.

18. In works upon physical science, the term "specific gravity" is used to express the ratio of certain bulks of the substance considered with reference to equal bulks of some other substance of known weight with which they may be compared. Water has been adopted as the standard of comparison in the case of the majority of solids or liquids, on account of its being little exposed to variation, and of its being easily compared with the relative weight of other substances. The specific gravity of gases, or æriform fluids, is, however, ascertained by adopting the the weight of dry atmospheric air as the standard. It thence follows, that the specific gravity of a solid, or of a liquid, is ascertained by dividing the weight of a portion of such substance by the weight of an equal bulk of water; and, similarly, the specific gravity of a gas is ascertained by dividing the weight of a given bulk of it by that of an equal volume of air. A table of specific gravity is here introduced, but it is particularly to be observed in using such tables, that the ascertaining of the weights of equal volumes of any two substances they may contain depends upon the weight of a definite unit of the term of comparison itself previously ascertained. For instance, if the unit of weight be a cubic inch of water, that of the substance to be compared with it will be found by multiplying the number of cubic inches it may contain by the weight of a cubic inch of water,

and by the tabular number. In the English tables the specific gravity of water is ascertained when it is at 62° Fahrenheit, and when the barometric pressure is equal to that of a column of mercury measuring 30 inches.

TABLE I. OF SPECIFIC GRAVITY OF BODIES (HUTTON AND CARR).

Platina, pure (Hutton)	. 23·400	Clay . . (Hutton)	. . 2·160
Standard gold	„ . 18·888	Brick . . „	. . 2·000
Standard silver	„ . 10·535	Common earth,,	. . 1·984
Cast lead . . „	. 11·325	Sand . . „	. . 1·520
Quicksilver . . „	. 13·600	Coal . . „	. . 1·250
Cast copper . . „	. 8·788	Box wood . „	. . 1·030
Gun metal . . „	. 8·784	Sea water . „	. . 1·030
Cast brass . (Carr)	. 8·395	Common water,,	. . 1·000
Iron, cast . . „	. 7·207	Ash . . „	. . 0·800
Iron, bar . . „	. 7·788	Maple . . „	. . 0·755
Steel, hard . . „	. 7·816	Oak . . „	. . 0·925
Tin . . . „	. 7·291	Elm . . „	. . 0·600
Zinc . . . „	. 7·196	Fir . . . „	. . 0·550
Glass, flint . . „	. 3·829		
Glass, white . . „	. 2·892	Sulphurous acid gas	. . 2·265
Glass, bottle . . „	. 2·732	Carbonic acid gas	. . 1·500
Serpentine . . „	. 2·988	Nitrous gas . . .	. . 1·194
Basalt . . . „	. 2·864	Hepatic gas . . .	. . 1·106
Marble . . . „	. 2·741	Oxygen gas . . .	. . 1·103
Granite . . . „	. 2·654	Nitrogen gas . . .	. . 0·983
Porphyry . . . „	. 2·765	Ammoniacal gas . .	. . 0·600
Flint . . . (Hutton)	. 2·570	Hydrogen . . . .	. . 0·084
Common stones „	. 2·520	Atmospheric air . .	. . 1·000

19. The property by which heavy bodies displace a quantity of water equal to their own volume, when their specific gravity exceeds that of the water itself, is usefully applied in calculations of various descriptions, if the specific gravity either of the water, or of the body, be known. Thus, inasmuch as the weight lost by the body when immersed (which may be represented by  $w$ ) is to its total weight in vacuo (or  $W$ ) in the same ratio as the specific gravity of the water (or  $s$ ) is to the specific gravity of the body ( $S$ ); or in another form as  $w : W :: s : S$ , it is easy to calculate any one of the unknown terms of the problem, if the others should be already known; or, indeed, as  $S = \frac{W}{w}$ , the knowledge

of the two latter terms will suffice to determine the others. Again, if a body float on a fluid, the part immersed (Q) bears the same proportion to the whole body (P + Q) as the specific gravity of the body (s) does to the specific gravity of the fluid (S); or  $Q : P + Q :: s : S$ . It is upon this principle that the *Hydrometer*, or the instrument for ascertaining the specific gravity of fluids, is constructed; for, evidently, when the same body floats on different fluids, the magnitude of the part immersed in the first is to the magnitude immersed in the second, as the specific gravity of the second fluid is to that of the first. The practical rule for ascertaining the specific gravity is as follows:—Let  $W$  = the weight necessary to sink the bulb of the hydrometer in one fluid, supposed to be water, and  $W \pm w$  the weight necessary to make it sink to the same point in the other. Then, as the specific gravity of water is usually taken as 1·000, the specific gravity of the other will be  $= 1\cdot000 \times \pm \frac{w}{W}$ .

When either the magnitude or the weight of a body is given, the other property may be ascertained from its specific gravity, thus:—If the magnitude  $M$ , and the specific gravity  $S$ , be known, the weight  $W = M \times S$ ; or the weight in grains and the specific gravity being known, the bulk or volume in cubic inches,

$B = \frac{W}{252576 S}$ . The magnitude of an irregular solid

and the capacity of an irregular vessel may be also ascertained from the property under consideration; for if the solid be weighed in air and in water, then, since a cubic foot of rain water weighs 1000 ounces, it is to the weight lost, as one cubic foot is to the magnitude required; or, again, if the vessel be weighed when empty, and when it is full of water, then the weight of one



cubic foot of water is to the total weight of the water, as one cubic foot is to the total capacity required.

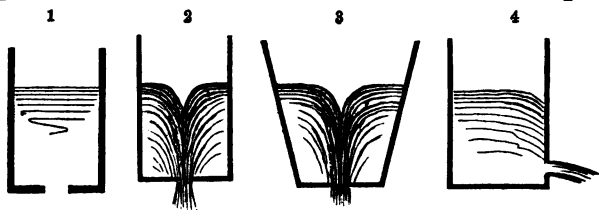
## HYDRAULICS.

20. We have seen that when a fluid is contained in a vase of any form, it exercises, in consequence of its gravity, pressure upon every portion of the surface of the vase, and perpendicular to the same. If, then, a vase be perforated, the fluid will escape with a certain velocity; and, at the same time, certain movements will take place in the fluid whilst in the interior of the vase, which we will proceed to notice.

21. When a small hole is made in the bottom of a vase, the molecules of the fluid move vertically to within a short distance of the orifice, supposing the top surface to be exposed to the direct influence of the atmosphere; but the other molecules flow towards the orifice from every direction. If the orifice be on the side of the vase, the molecules of the fluid equally move towards it, as far as the level of the bottom of the orifice itself; so that, in every case, their motion is towards the orifice from every direction; and as the same quantity of fluid must pass through the same space in the same time, if the pressure be uniform, the mean velocity of each such quantity must be in the inverse ratio of the capacity it occupies in the vase.

22. The upper surface of the fluid in a vase, such as we have above considered, is not always terminated by a horizontal plane. Thus, for instance, when the fluid escapes vertically through an opening in the bottom, and the level has fallen nearly to that of the orifice, the upper surface of the fluid assumes the shape of a concave funnel, whose apex is in the centre of the orifice. If the fluid originally had a rotary motion, or if the vase itself were conical, the funnel formed by the upper

surface of the escaping fluid would be developed at an earlier period than if the sides were vertical, and no extraneous motion had been given. If, moreover, the orifice were lateral, the complete funnel-shaped depression would not be formed, but the surface of the liquid would be depressed; as in the accompanying figures, 1, 2, 3, and 4. These movements depend



upon the form of the vases, the height of the fluid in them, and the position and dimension of the orifices. Hitherto mathematicians have not succeeded in explaining satisfactorily the general laws under which they take place.

23. In escaping from an opening in a vase, the fluid-vein assumes the form of a prism, whose base would be the orifice itself, but whose sides recede gradually until they attain a distance from the orifice equal to about half its diameter; at this point, the diameter of the fluid-vein would only be 0·6 or 0·7 of that of the orifice. This diminution in the sectional area of the fluid-vein is known by the name of *its contraction*; and it takes place in whatever direction the fluid may escape, but under slightly different conditions, dependant upon the action of terrestrial gravitation. Thus, when the fluid-vein escapes vertically downwards, the prism contracts to a greater distance than usual, because the velocity of the fall of each horizontal layer increases in proportion to the space fallen through, and therefore the distance between any two such layers

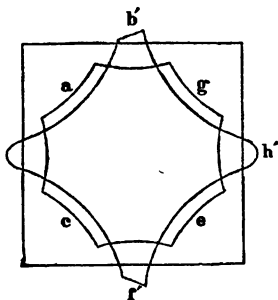
must also increase. Again, when the jet escapes upwards, the prism enlarges immediately after the extreme point of contraction has been passed, because the velocity diminishes. In all cases, however, the resistance of the air divides the jet into drops of greater or less volume, when it has reached a certain distance from the orifice. In vacuo, the jets, if they be not vertical, would describe a parabolic curve in falling, as solid bodies do under similar circumstances.

24. The contraction of the fluid-vein does not appear to arise from any diminution of the volume of the fluid itself, but rather from the fact that the molecules of the fluid leave the orifice with different parallel velocities. Those which pass through the central parts of the orifice are not exposed to the retarding influence of the friction which necessarily takes place upon the perimeter; and they, therefore, must have a greater initial velocity than the molecules which were thus in contact with the sides. Moreover, the velocity of efflux in the filaments of the vein is affected by the various inclinations under which they approach the orifice; in a short time, however, after leaving the vessel the velocity becomes equalised throughout the column, and it would remain constant, if the pressure upon the orifice and the resistance of the air did not interfere with it.

25. When the jet is vertical and downwards, and the liquid has originally a rotary movement, a species of funnel is formed in the interior of the vase, and the liquid leaving it assumes a similar form, but its apex is precisely in the opposite direction to that of the funnel in the interior. If the sides of the orifice be not perfectly even, and the liquid in the interior be impressed with a rotary motion, the fluid-vein, in escaping, often assumes the form and appearance of a

spiral column. When the orifice is polygonal, or of any other than a circular form, the outline of the fluid-vein is more complicated, but substantially the results are not different. If the various parts of the orifice should not be symmetrical, the vein would not retain the form it had on leaving the orifice; but it changes continually as the distance from that orifice increases: thus, immediately after leaving the orifice, the faces corresponding with the rectilinear sides become hollow, and the concavity increases in proportion to the distance; whilst, after a time, the edges corresponding to the angles are splayed off, and finally they disappear altogether. Thus, MM. Poncelet and Lesbros ascertained that the form of the vein, leaving an orifice perfectly square, and measuring 8 inches on each side, presented the section *a, c, e, g*, at a distance of 6 inches from the orifice; and the section *b, d, f, h*, at a distance of one foot. This last was the smallest section, and its area was 0.562 to 1 of the orifice: whilst the effective discharge was 0.605 to 1 of that indicated by theory. The head of water during the observations referred to was maintained constantly at 5 feet 7 inches. In this case the fluid-vein seems to have made the eighth of a revolution upon its axis; and the researches of Bidone upon the phenomena of jets of water show that many other interesting remarks are to be made upon them. The reader who desires to study the subject is referred to the very interesting work by this author, under the title of "*Expériences sur la forme et sur la direction*

Fig. 5.



des veines et courants d'eau lancés par diverses ouvertures." For the present it may suffice to observe, that if the jet should be of any important length, a series of contractions and expansions takes place in it; which are accompanied by changes in the transverse section when the orifice is polygonal.

26. The velocity with which a fluid leaves an orifice, observed at the orifice itself, is at the commencement imperceptible; it increases for a certain period, after which it remains constant, if the level of the fluid should continue the same in the vase; or it decreases, if the level should be lowered. Whatever be the form of the opening, or whatever may be its size compared with the transverse section of the vase, so long as the water in the latter remains at the same level, the velocity with which the fluid escapes will follow the same constant law.

27. When the orifice through which water flows from a vessel is made in a thin plate; or when the thickness of the side of the vase does not exceed the smallest dimension of the orifice, and is, at a maximum, only from 2 to  $2\frac{1}{4}$  inches; the rate of flow, when no initial velocity exists, has been accurately expressed by Torricelli in the formula

$$V = \sqrt{2 g h}; \text{ from which, } h = \frac{V^2}{2g}.$$

In this formula,  $V$  = the theoretical velocity; but the real velocity is found to be between  $V - 0.1 V$  and  $V - 0.2 V$ ; the diminution of the velocity of the whole jet being attributable to the friction of the water against the sides of the orifice, and to the resistance of the air. In the formula,  $h$  = the height of the liquid in the vase above the centre of gravity of the orifice; and  $g$  = the acceleration of motion due to gravity, in a second, which is, in London, considered to be  $32\frac{1}{8}$  feet.

The velocity in this case is that which a heavy body would acquire in falling in vacuo through  $h$ ; and as the velocity is proportional to the square root of the height of the liquid above the centre of gravity of the orifice, if the height be quadrupled evidently the velocity will only be doubled.

28. When the liquid flows through an orifice, whose length is  $1\frac{1}{2}$  times its smallest transverse dimension, at a minimum; or when an ajutage is employed, whose length is equal to two or three times the smallest dimension of the orifice; the formulæ for calculating the velocity become  $V' = 0.82 V = 0.82 \sqrt{2 g h}$ ;  $V'$  being the real velocity with which the water flows, and the other notation as before.

29. The velocity would be modified if the two faces of the orifice should be under water, and it would be represented by the formula,  $V = \sqrt{2 g h (h - h')}$ , in which  $h'$  = the height of the water in the second recipient, and  $(h - h')$  = the difference of levels of the water in the two vessels, retaining the preceding significations of  $V$ ,  $g$ , and  $h$ . If the discharging vessel should be subject to any pressure, the formula would become  $V = \sqrt{2 g h (h + h')}$ , in which  $h'$  would represent the pressure expressed in the height of a column of the liquid.

30. If we leave out of account the diminution of the velocity, and the contraction of the fluid-vein near the orifice, the theoretical discharge would be  $Q = SV$ , in which  $Q$  = the quantity discharged per second,  $S$  = the sectional area of the orifice, and  $V = \sqrt{2 g h}$ . But the quantity which really flows from any orifice differs considerably from that indicated by theory, and it is usually expressed by the formula  $Q = K SV$ , in which the new term  $K$  = the coefficient of discharge, or the ratio of the real effective quantity flowing from

the orifice to the theoretical one. The value of this coefficient depends upon the pressure upon the orifice, its form, and its position in the sides of the vase.

31. The greatest contraction takes place when the orifice is removed from the bottom, and the sides of the vase, by a distance at least equal to 1 or  $1\frac{1}{2}$  times its own smallest dimension; and under these circumstances the contraction takes place all round the fluid vein. But if the sides of the opening should be in the prolongation of the sides of the vase, the ordinary co-efficient of contraction requires to be multiplied by 1.135, in the case when the prolongation exists on one side; by 1.072 when it exists on two sides; and by 1.025 when it exists on three sides. MM. Poncelet and Lesbros have determined the values of the coefficient of discharge for rectangular orifices with the greatest contraction; and these values are given in the Table II. in which the dimensions are given in

TABLE II.

Head over Center.	Height of Orifice.					
	8 in.	4 in.	2 in.	$1\frac{5}{8}$ in.	$\frac{1}{2}$ in.	$\frac{1}{8}$ in.
$\frac{18}{32}$ in.	...	...	...	...	...	0.712
$\frac{19}{32}$ in.	...	...	...	0.644	0.667	0.700
$1\frac{5}{16}$ in.	...	...	...	0.644	0.663	0.693
$1\frac{7}{16}$ in.	...	...	0.624	0.643	0.661	...
2 in.	...	...	0.625	0.643	0.660	...
$2\frac{9}{16}$ in.	...	0.611	0.627	0.642	...	...
$3\frac{1}{8}$ in.	...	0.612	0.628	0.640	...	...
4 in.	...	0.613	0.630	0.638	...	...
$4\frac{3}{4}$ in.	0.592	0.614	0.631	...	...	...
6 in.	0.597	0.615	0.631	...	...	...
8 in.	0.599	0.616	0.631	...	...	...
1 ft.	0.601	0.616	...	...	...	...
1 ft. 8 in.	0.603	0.617	...	...	...	...
3 ft. $3\frac{1}{2}$ in.	0.605	...	...	...	...	...

English feet and inches. They are equally applicable for other forms of orifice, without any inward projection,

provided that the smallest dimension be equal to that of the height given in the table ; and they are equally applicable when the discharge takes place in the open air, or under water. It is important, however, to observe that, if all other conditions remain the same, the contraction diminishes in proportion to the thickness of the orifice, for when the latter is considerable it acts to a certain extent as an *ajutage* ; and that when the sides of the vessel are convex, outwardly, the discharge will be increased ; whilst, on the contrary, the discharge will be diminished if the sides should be concave.

32. In the sluices of lock gates, the cills of which are generally upon the floor of the lock chambers, the coefficient of discharge is always 0·625, whether the sluice work in still water or not. Formerly, it was usual to adopt the coefficient 0·55 when two sluices were used ; but more recent experiments appear to prove that the real coefficient should be, as above, 0·625. With inclined sluices, such as those used in the races of water-mills, with Poncelet's wheels (to be noticed hereafter), the lower and side faces of which sluices are in the prolongation of the reservoir, the coefficient is 0·74, if the upper face should have an inclination of 1 to 2 ; and of 0·80, if the inclination should be as 1 to 1 : the sectional area being obtained from the vertical height of the opening, not from the actual area of the opening itself.

33. When water falls over a weir, its effective discharge is stated by Poncelet to be represented by the formula,

$$Q = K L H \sqrt{2 g H}. \quad \text{In which}$$

$Q$  = the effective quantity falling over the weir ;

$K$  = the coefficient of discharge, stated by him to be = 0·405 ;



$L$  = the width of the overflow ;

$H$  = the height of the water above the cill of the weir ; this height must be ascertained at a point where the level of the water is not affected by the contraction of the fluid-vein, which would usually be from 4 to 8 feet above the overflow. In Table III. are given the various coefficients for different values of  $H$ , observed by MM. Poncelet and Lesbros ; and it further appears from their investigations, that the usual coefficient 0.405 becomes 0.42, when the clear opening of the overflow is of the same width as the leading channel, and when the depth of the latter corresponds nearly with  $H$ . If we call the thickness or depth of the sheet of water falling over  $h$ , it will be found that  $H = 1.178 h$ , when the clear opening of the overflow is  $\frac{2}{3}$ ths of the width of the feeding channel ; and that  $H = 1.25 h$ , when the two widths are equal.

TABLE III.

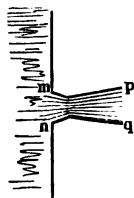
Height over weir .....	$\frac{19}{32}$ in.	$\frac{19}{16}$ in.	$1\frac{5}{16}$ in.	$1\frac{7}{16}$ in.	$2\frac{1}{16}$ in.	$3\frac{1}{8}$ in.
Value of coefficient...	0.424	0.417	0.412	0.407	0.401	0.397
Height over orifice ...	4 in.	6 in.	8 in.	$8\frac{1}{2}$ in.		
Value of coefficient...	0.395	0.393	0.390	0.385		

34. When cylindrical tubes are added to an orifice in any vase, or reservoir, the discharge through the former will be found to be greater than would have been the case if the orifice had been left in its natural condition, supposing, of course, that the head of water and the dimensions of the orifice remain identical. This increased discharge will not, however, take place unless the water should fill the orifice, and this will occur when the length of the additional tube, or of the *ajutage*, as it is called, is three or four times its dia-

meter; on the contrary, the orifice will not be filled when the length of the tube is less than that of the contracted vein, produced by the escape of the water. The increase in the discharge produced by a cylindrical ajutage, of the proper length to ensure its being filled, and in which that length does not exceed four times the diameter, is in the proportion of 1.33 to 1.00 of the ordinary discharge through an orifice in the plane sides of the vessel.

35. The effective discharge may be still further increased by making the ajutage of the form represented in the accompanying sketch, provided the liquid fill it entirely. This form of ajutage consists of two portions of cones upon the same horizontal axis, but with their apices in opposite directions. The first portion has the form of the contracted vein; the length of the second is three times that of the first; and the opening *m*, *n*, of the first, in the side of the vessel, is  $\frac{7}{8}$ ths of *p*, *q*, of the second. The effective discharge through an ajutage of this form is in the proportion of 3 to 2 of the discharge which would take place through a simple aperture in a thin plate.

Fig. 6.



36. When water flows through long pipes the velocity of its flow is increased by the effect of gravitation, if the pipes have a general fall; and as the liquid column is prevented from changing its form by the adherence to the sides of the pipes, and by the resistance of the air, the lower filaments of the liquid transmit a portion of their velocity to the upper ones, and thus establish a general uniform velocity which increases in proportion to the length of the pipes up to a certain point, beyond which the friction upon the perimeter of the

pipes stops the increase. In horizontal pipes this friction repeated upon a great length tends continually to diminish the velocity; so that, if the length be considerable in comparison with the initial velocity, the liquid might, under some circumstances, hardly flow at all in such pipes. Eytelwein states that, in consequence of the existence of this friction, the head of water, producing motion in a pipe, may be considered to be divided into two parts, one of which serves to generate the velocity, and the other to overcome the friction. This latter portion must, therefore, be directly as the length of the pipe and the circumference of the section (or, as the diameter of the pipe), and inversely as the contents of the section (or as the square of the diameter). This part of the subject will be found treated in greater detail in the subsequent chapter of this work, devoted to the consideration of the water supply of towns; to which it has been reserved on account of its more intimate connection with that branch of practical hydraulic engineering.

37. It used to be considered that the rate of flow of water in pipes was not sensibly modified by the nature of the materials of which they are formed, or by their mechanical structure, so far as regards the smoothness of the interior; and that the flow depended alone on the length and diameter of the pipes. The costly, but, at the same time, the ridiculous, experiments made by the Trial Works Committee of the first Metropolitan Commission of Sewers appeared to confirm this opinion; but, latterly, M. Darcy has seriously called it in question, and from his "*Recherches Expérimentales relatives au mouvement de l'eau dans les tuyaux*," and from the report of MM. Morin, Combes, and Poncelet, who had been appointed by the Académie des Sciences to examine the above-named

*Mémoire*, it would appear that the nature and the state of the surfaces, over which water flows, exercise a notable influence upon the discharge of pipes. The resistance which the latter oppose to the rate of flow, increases in proportion to the length, and is considered to be in the inverse ratio of the diameter, according to De Prony, and the earlier writers on hydraulics; but M. Darcy's researches throw some doubt also upon the generally received opinions on this point, for he has arrived at the conclusion that the influence of the diameter upon the rate of discharge was greater than would be indicated by De Prony's formula; and that this formula gave results in excess of those actually observed with small diameters, whilst the results were equally below the real fact when large diameters were experimented upon. Under all conditions of the diameter, however, curves, or deviations from the right line, in the pipes have a sensible influence in retarding the velocity of flow. If they should be of a nature to cause a severe shock, it is even possible that they may so effectually disengage the air in suspension in the water as entirely to interrupt the flow, unless a blow-off, or escape for the air, be provided. M. Darcy has devoted a chapter of his work upon the history of the water supply of Dijon, to the discussion of the influence of the air upon the discharge of a pipe, to which we may have occasion to return in a subsequent part of this work.

38. In capillary tubes, as might naturally be expected, the velocity of flow is more affected by the resistance of any confined air than it is in those whose diameter is greater, and the retarding influence of the friction upon the contour is also necessarily more important, because the friction only affects those portions of the liquid which touch the contour of the tubes, and it

must, therefore, be the greatest when that contour is in immediate proximity to the axis.

39. Bernouilli observed that, when liquids flowed in pipes, the pressure they exercised against the sides of the latter, was always less than the pressure they would exercise if they were in repose. The effective pressure is stated by him to be equal to the height of the liquid producing the head at the point observed, diminished by the height of the liquid able to produce the velocity actually existing at that point. From this it will follow, that the pressure will always be in the inverse ratio of the velocity, and that it would be annihilated if the latter were really the velocity due to the head over the point of observation. This law has been verified by a sufficient number of experiments to entitle us to consider it to be correct.

40. In open channels, as contradistinguished from pipes, the fact of the upper surface being open modifies, to a serious extent, the conditions of the flow of any water they may convey; and it has been found that, whatever be the section of a channel, if a uniform velocity be once established in it, the same quantity of water will be discharged at the lower end as enters at the upper; consequently in any transverse section of the channel the same quantity of water must pass in the same period of time. It follows from this, that the velocity of the current must increase in proportion to the diminution of the area of the channel, if the discharge remain the same; on the other hand, that the velocity must diminish in proportion to the increase of the area. As the rate of flow is, in channels, produced by the action of gravitation, it must evidently increase with the inclination; and in order to maintain an equable discharge, the several conditions of the dimensions and of the inclination, both of the channels

and of the water, must co-ordinate. In a channel with a uniform inclination and section, however, the rate of flow also soon becomes uniform; because the friction of the sides destroys the increase of velocity which would otherwise be produced by gravitation—at least this is the case with the inclinations and dimensions ordinarily given to water channels. It also follows, from the effects of the friction upon the wet contour, that the velocity of all the molecules in the transverse section at any point is not equal; those which are in contact with the sides of the channel are retarded in their flow, and, in their turn, they retard the flow of the molecules immediately around them. Of course, under these circumstances the maximum velocity exists at the surface and upon the axis of the current. From the experiments of Dubuat it appears, that the mean velocity of any stream in an open channel, represented by  $v$ , may be expressed by the formula  $v = c V$ , in which  $V$  represents the velocity upon the axis, and at the surface; and  $c$ , a coefficient varying according to circumstances between 0.76 and 0.891. It is usual therefore in practise to consider that, for surface velocities varying between 8 inches and 5 feet per second,  $v = \frac{4}{5} V$ ;

or that  $V = 1.25 v$ . But in large rivers these formulæ would give results far in excess of those actually found to exist; for it has been ascertained that in the Seine  $v = 0.62 V$ ; and M. de Raucourt found that in the Neva  $v = 0.75 V$ .

41. The German engineers who have examined this subject, have found that the mean velocity of all the fluid-veins met by the same vertical line in any part of the section of a river, bore a proportion to the velocity at the highest point on that line varying between 0.88 and 0.92. From the experiments made

by M. Defontaine upon the flow of the Rhine, this ratio would appear to be 0·88 in that river.

42. Dubuat concluded from his own observations that the velocity at the bottom of a channel, calling it  $U=2v-V$ , in which formula  $v$  and  $V$  retain the same signification as above; and from this, if  $V=1\cdot25v$ ,  $U=0\cdot75v$ ; or  $v=1\cdot33U$ . In the formation of a water-course therefore,  $U$  must be regulated so that its velocity should not be such as to remove the materials of the bed; and Dubuat has drawn up a short table, as follows, of the rate of flow able to carry forward the various substances named:—

	speed per second.
River mud, semifluid silt . . . . .	0 ft. 3 in.
Brown pottery clay . . . . .	0 3½
Common clay . . . . .	0 6
Yellow sand loamy . . . . .	0 8½
Common river sand . . . . .	1 0
Gravel, size of small seeds . . . . .	0 4½
„ „ of peas . . . . .	0 7½
„ „ of beans . . . . .	1 0½
Coarse ballast . . . . .	2 0
Sea shingle, about 1 inch diameter . . . . .	2 2
Large shingle . . . . .	3 0
Angular flints size of hens' eggs . . . . .	3 3
Broken stones . . . . .	4 0
„ agglomerated, or soft schistous rocks . . . . .	4 4
Rocks with distinct layers . . . . .	6 0
Hard rocks . . . . .	10 0

The other dimensions of a water-course would be ascertained from the following formulæ for channels of a uniform inclination and a constant section.

43. In these cases calling  $Q$  the discharge,  $S$  the sectional area, and  $v$  the mean velocity of the water, and

taking the dimensions in yards and the decimal parts of yards, we have  $Q = S v$ ; from which we have also  $v = \frac{Q}{S}$ .

The inclination will be ascertained (calling it  $I$ ) by the formula  $I = \frac{P}{S} (av + bv^2)$  according to De Prony. In the latter formula  $P$  represents the wet contour, or the developed length of the wetted surface;  $S$ , the sectional area as before; and  $a$  and  $b$ , numerical coefficients which De Prony makes respectively 0.0000444 and 0.000309. Eytelwein was induced, from some observations, to change these coefficients, and to make  $a = 0.000024$ ,  $b = 0.000365$ . But it would appear that Eytelwein's values of  $a$  and  $b$  are only correct for large rivers; whilst for channels whose sectional areas would not exceed 10 yards superficial, De Prony's values are the more correct.

44. If we call the quotient of the transverse section of the watercourse  $S$  by the wet contour  $P$ , the *mean radius*, and represent it by  $R$ , we have  $R = \frac{S}{P}$ ; and the formula of De Prony gives us, replacing  $a$  and  $b$  by the values he has assigned to them,

$$R I = 0.0000444 v + 0.000309 v^2,$$

from which we obtain,

$$v = \sqrt{0.005163 + 3233.428 R I} - 0.07185, \text{ or nearly}$$

$$v = 56.86 \sqrt{R I} - 0.072.$$

De Prony's formulæ of course are expressed in French mètres and their subdivisions. Playfair, in his *Outlines of Natural Philosophy*, translates the last-cited formula for the velocity in English feet as being

$$v = -0.1541131 + \sqrt{0.023751 + 32806.6 R I}.$$

From these formulæ it will, therefore, be easy to ascertain the value of  $v$ , if  $I$  and  $R$  be known; or to



ascertain the inclination  $I$  requisite to obtain such a velocity that  $v = \frac{Q}{S}$ . The value of  $R$  depends upon that of the section  $S$ , and the form of this section ; the latter being usually regulated by local considerations. If the channel should be executed in wood or in masonry, it would, generally speaking, be preferable to make the sides vertical, and the width equal to twice the depth of the water so as to render the wet contour, and consequently the surface producing friction, as small as possible. In channels of earthwork, or ordinary canals, the slopes of the sides vary according to the nature of the materials employed, and the width usually ranges between four and six times the depth of the water.

45. De Prony's formula for ascertaining the velocity will serve, not only to calculate the discharge of a channel of a uniform inclination and constant section, but also to gauge any stream, provided a length of about 500 yards can be found upon it, where those conditions of inclination and section are fulfilled. A cross-section of the stream will, in this case, give its area and its wet contour, and by dividing the former by the latter the mean radius  $R$  will be found ; a longitudinal section will give the total inclination of the regular portion of the stream ; and this inclination, divided by the developed length of the axis, will give the partial inclination in each unity of length. If the section of the stream should not be constant (which is indeed almost always the case with natural channels), a certain number of cross-sections must be taken in the portion where the stream is most regular, from which an average must be deduced, for the purpose of furnishing the elements for calculating the wet contour and the mean radius. The inclination is then to be ascertained from the mean velocity  $v$ , and the discharge

will be found by the ordinary formulæ. Should it happen, however, that the stream is divided into two portions, one of which is very deep and comparatively speaking narrow, whilst the other is shallow and broad, it would be preferable to consider the stream as though it were divided into two distinct branches, and to calculate the discharge of each of them separately.

46. It is possible also to ascertain the volume of a river by determining the maximum velocity of the surface, and the average sectional area; for the discharge will be found to be nearly  $Q = S (0.8V)$  which latter term we found to be the expression for the mean velocity  $v$ . It is essential in all such calculations that great care should be taken not only in ascertaining the cross-sections, but also that the floats used to determine the velocity should be thrown into the stream at some distance above the points of observation, in order that they may really acquire the average velocity of the water during their passage.

47. The preceding observations, it must be observed, only apply when the volume of water passing an orifice, or through any given portion of the channel of a stream, is such as to maintain a constant head or pressure. If, however, the discharge should be greater than the supply, the level of the water above the orifice, or section, will fall, and consequently the head or pressure producing the velocity will be reduced. The value of  $H$  in such cases will, therefore, have to be modified so as to express the effective head influencing the discharge during the entire operation. It has also been assumed, that the discharge takes place in the open air, and without encountering any resistance on the under side; - but in the case of one reservoir discharging its waters into another, not only does  $H$  require to be modified, but a new term is required to

be introduced, for the purpose of representing the resistance of the water in the lower reservoir as it rises above the orifice of communication.

48. Morin gives a rule for ascertaining the discharge when a variable head, as above described, exists over the centre of an orifice, which is sufficiently simple for ordinary practice, and may be stated as follows: A vertical rule is to be placed in the upper reservoir, and upon it are to be measured the levels of the water corresponding to equal intervals of time; for ordinary purposes five observations will suffice. Then, calling  $L$  the width of the orifice;  $E$ , its height;  $m$ , the coefficient of discharge ascertained from the arithmetical mean between the values corresponding with the greatest and least heads observed;  $h_1, h_2, h_3, h_4, h_5$ , the levels corresponding with equal intervals of time  $t$ ; and  $Q$ , the volume discharged in the whole time, or in this case,  $4t$ ; we have  $Q = 1.476 m L E t (\sqrt{h_1} + \sqrt{h_5} + 4(\sqrt{h_2} + \sqrt{h_4}) + 2\sqrt{h_3})$ : or, in other words, if it be desired to ascertain the volume of water discharged in a given time by an orifice, with a load upon its summit of a variable nature, after having as above observed the variations of level, the rule is—to take the square root of each of the heads over the orifice; to the sum of the greatest and least of these square roots add four times the sum of the square roots of the heads of the even pair of the heads observed, and twice the sum of the square roots of the heads of the uneven pair; multiply the total sum by the time which has elapsed between two observations by the area of the orifice, by the coefficient discharge, and by 1.476. This formula becomes, when the flow of water over a weir is considered,  $Q = 0.598 L t (h_1 \sqrt{h_1} + h_5 \sqrt{h_5} + 4(h_2 \sqrt{h_2} + \sqrt{h_4} + h_4 \sqrt{h_4}) + 2h_3 \sqrt{h_3})$ ; and when the orifice may be covered with water on the underside,

the heads  $h_1$ ,  $h_2$ , &c., must be replaced by the differences of the heads on the upper and under sides at the same periods of observation; that is to say,  $h_1$  becomes  $H_1 - h_1$ ; and  $h_2$  becomes  $H_2 - h_2$ , calling  $H$  the head producing pressure on the upper, and  $h$  that on the under side of the orifice.

49. In all rivers there will be found to exist a greater or lesser extent of comparatively speaking still water in immediate proximity to the bank; and in this part of the stream may also be observed a series of small eddies, produced by the impulsion of the current. The principal direction of these eddies appears even to be opposed to that of the current, and again, when any obstacle is offered to the onward flow of the latter, the water becomes heaped up, as it were, and in this case also a kind of return in the current takes place, owing to the change of direction in the flow of the water. A dyke or embankment in a river will produce this effect; as will also any construction which diminishes the water way, such as groins, bridges, &c. There is no universally received word in the English language which expresses this effect, and it may, therefore be as well to adopt the French word "remous" to express simultaneously the increase of height and the change of direction, produced in a current by the intervention of any obstacle to its flow.

50. In the case of a dam across the whole width of a stream, the horizontal section of whose bed is represented to an exaggerated scale by the line  $A B$ , and the dam by  $E F$ , the water will rise on the upper side, to fall subsequently over the edge of the dam. The fluid mass represented by  $A a a C D$  will here represent the remous; and its greatest depth, excepting in so much as it is modified by the conditions mentioned in the next sentence, will exist immediately over the



and in large remous this sloping, or inclination of the surface, will begin at a considerable distance on the upper side of the dam. The height of the remous, at any given distance from the edge, will necessarily result from the nature of the curve assumed by the surface of the water. This is essentially a hyperbola, whose summit is at  $A'$ , whose axis is  $A C$ , and which is nearly tangential to a line passing through  $A$ , at such a distance that  $E G = \frac{2 E H}{b}$ ; in which expression  $b$  = the length of the dam.

51. During the investigations conducted by the Italian engineers for the purpose of discovering a simple self-acting gauge to measure the waters supplied for the irrigation of that country, a very interesting and important fact was observed, which indicated that the ordinary laws of hydrostatics applicable to the level of water in communicating vases, were modified to some extent when the water was set in motion. It was then ascertained that, in a vase constantly supplied, but divided into two portions by a diaphragm susceptible of being moved vertically, and with a discharging orifice on one side, a constant difference of level existed in the surfaces of the respective portions of the reservoir so long as the water flowed; and that this difference of level was greater in proportion as the opening of the diaphragm was less, compared to that of the orifice. And it was also observed that if, by any change in the direction of the supply or of the flow, the level were made to alter on either side of the diaphragm, the corresponding variations in the level upon the two sides continued always to be proportional to the respective differences of level first established. This law is not affected by the introduction of two or more diaphragms, for a similar

variation of level takes place between each of them, and it is maintained so long as the water flows. Of course, if the discharge cease, the hydrostatic pressure will cause the water to assume the same level in all the communicating compartments, whatever be their number.

52. If we suppose a fluid to be contained in a reversed syphon, each of whose branches is of the same diameter, the fluid will be found to stand at the same level in both of them; and if, by any means, the fluid column be first raised in one of the branches, and then allowed freely to resume its natural position, it will commence its movement by falling below the original level, in consequence of the velocity acquired; it will immediately afterwards remount above that line, and continue to oscillate about it for a certain time. These oscillations are found to be isochronous; and if the branches of the syphon should be vertical, their duration will be equal to that of the beats of a pendulum, whose length is equal to half the total height of the liquid column.

53. When any point on the surface of a pool of still water is disturbed, a series of small waves is formed around it, which extend with great rapidity. These waves are found to be of two sorts: the first are formed at the same moment in great numbers, and are propagated in every direction with a uniformly increasing velocity, like that of the fall of heavy bodies, and the distance between the summits of any two waves increases in the direct ratio of the time elapsed since their formation; whilst the heights decrease in the inverse ratio of the square of the time, when the liquid is contained in a channel of a constant width—or, according to the fourth power of the time when the liquid is free. The second sort of waves also rises in infinite numbers, and at the same time; but the waves

are propagated uniformly with a velocity proportionate to the square root of the diameter of the surface exposed to the shock; the heights of the surface decrease in the inverse ratio of the square root of the time, or of the first power thereof, according as the liquid may be contained in a channel, or be entirely free. The second description of waves is more appreciable than the first, especially near the point of origin; and any wave which is formed thus on the surface of a liquid mass, is propagated to a considerable depth in the interior.

54. When waves of either of the above-mentioned sorts come in contact with a fixed body, they are interrupted in a portion of their course, and that portion of the wave which strikes the resisting body, is reflected back upon itself, and propagated in a direction opposite to the one it originally followed; it is, however, re-formed beyond the obstacle, if the latter be isolated in the midst of the fluid, and it extends beyond it as though the wave had never been interrupted. When several centres of disturbance are formed in a piece of still water, the respective series of waves may be observed to cross one another without producing any very decided interference. These observations, however, are only applicable to small bodies of water; in the subsequent parts of this treatise, attention will be more particularly called to the laws affecting the formation of the waves of the sea and of their mutual interference.

55. Bodies moving in fluids meet with two species of resistance: the one arising from the movement communicated to the portions of the liquid successively displaced; and the other, from the power necessary to separate the parts of the liquid between which the bodies move. Up to a certain velocity, the resistance



of fluids from the first cause is found to be proportional to their density; to the square of the sectional area of the bodies moving in them, modified to a considerable extent by the forms of such bodies, and to the square of the velocity. The resistance arising from the cohesion of the fluid was found by Coulomb to be proportional to the velocity, and to be independent of the nature of the surface of the body; he also found that the pressure to which the fluid is exposed, is equally without influence upon the value of the resistance. Thus it would appear, that any body moving in a liquid meets with a resistance composed of two terms: the one due to the inertia of the liquid, and increasing as the square of the velocity; the other due to the cohesion of the liquid, increasing simply with the velocity.

56. The researches of Mr. J. Scott Russell upon the movement of canal boats at high velocities, would induce us to believe that when the velocity of bodies of that description exceeds 13 feet per second, some new, and hitherto but imperfectly understood, laws come into operation. Our present knowledge of the subject may, perhaps with some reserve, be thus expressed, in the words of the Report of the British Association for the Advancement of Science.

After establishing the fact that the movement of a canal barge, or of any solid body, in a channel of still water gives rise to a displacement of the water surface, which advances with an undulatory motion in the same direction as the body itself, and which Mr. Russell distinguishes by the name of the *wave of displacement*; he proceeds to say that: "The resistance of a fluid to the motion of a floating body will rapidly increase as the velocity of the body rises towards the velocity of the wave of displacement caused by the said motion,

and it will be greatest when the two velocities approach equality.

“When the velocity of the body is rendered greater than that due to the wave, the motion of the body is greatly facilitated. It remains poised on the summit of the wave in a position which may be one of stable equilibrium; and this effect is such that, at a velocity of 9 miles per hour, the resistance is less than at a velocity of 6 miles per hour behind the wave. The velocity of the wave is independent of the width of the fluid, and varies with the square root of its depth.

“It is established that in every navigable stream there is a velocity at which it will be more easy to ascend against the current, than to descend with the current. Thus, if the current flow at the rate of 1 mile per hour in a stream 4 feet deep, it will be easier to ascend with a velocity of 8 miles per hour on the wave, than to descend with the same velocity behind the wave. The velocity of the wave of displacement (which advances in the direction of movement of the floating body) is about eight miles per hour.”

It must not, however, be understood that the conclusions of the British Association in this matter are universally received as correct; for not only have the practical results of the attempts hitherto made to apply the laws thus enunciated been such as to inspire serious doubts with respect to them, but the direct experiments of Generals Morin and Poncelet on the resistance of water to bodies moving in it led those able observers entirely to reject the theories of Mr. Scott Russell upon which those conclusions were founded. M. Bourgois, in a recently published *Memoire “sur la resistance de l'eau au mouvement des corps”* (Paris, 1857), adopts the views of M.M. Morin and Poncelet; and indeed there seem to be very grave

reasons for believing that, in spite of the merited authority of the members of the British Association, they were in error in supposing that any new laws with respect to the resistance of fluids were to be observed, so long at least as the velocity of movement did not exceed 10 miles per hour. The influence of the bottom and of the sides of a canal, as well as that of the wave of displacement itself, upon the resistance of the fluid to an advancing body, are so great, however, as to render it extremely difficult to discover any precise expression of that resistance, or the laws under which it acts.

57. Projectiles, when they strike the surface of a liquid, meet with a resistance which diminishes their velocity and changes the direction of their path. The intensity and direction of this resistance depend upon the form of the projectile and its velocity. At all times, however, it tends to raise the direction of movement and to carry it towards the surface of the liquid; and if the original direction of the projectile should only be slightly inclined towards the horizontal line, the shock may even cause the projectile to rebound, in the same manner in which it would have rebounded from the surface of a solid body. It is thus that stones, thrown from a small angle, or bullets fired from batteries near the water line rebound, or *ricochet*, a great number of times before their velocity is sufficiently retarded to allow of their sinking permanently below the surface of the water by the ordinary effect of gravitation.

58. When a fluid is in motion a certain portion of the force by which it is animated may be employed for the purpose of driving a machine: but evidently the motive power thus applied, must be only that portion attributable to the gravity of the water itself; for if it

were necessary to create the power by the application of extraneous force, it would evidently be preferable to apply that force directly to the machine itself. In the industrial arts, then, water is only applied as a motive power when it flows in an inclined channel, or when it falls suddenly from a height. But it must be observed that, whatever be the nature of the intermediate machinery employed to transmit the power of the water, a portion of that power must always be lost: 1, because the whole velocity of the water cannot be destroyed, or else the water after producing its effect upon the machinery could not flow away; and 2, because the machine transmitting the power of the water, has a motion and a velocity proportionate to the latter, which consequently can only act by the excess of its velocity over that of the machine.

59. Water may act in several manners to produce motion, either by percussion, by pressure, or by re-action. It acts by percussion when it strikes the portions of any machine placed in its course, and when, after having communicated its movement to the machine, it flows away immediately after producing the shock; float wheels placed in a current are illustrations of this action. Water acts by simple pressure when, having no initial velocity, or one which is very small and only equal to that of the body on which it acts, it moves the latter merely by its weight; as in the case of bucket wheels, when the velocity of the periphery of the wheel is equal to that of the stream. Water acts both by percussion and by pressure, when it falls upon a bucket wheel with a velocity greater than that of the wheel itself. Lastly, water produces its effect by re-action in turbines, or in what are called for this very reason re-action mills. In the case of the hydraulic press the law by which a liquid enclosed in a

vessel on all sides is able to transmit, to every portion of its bounding surface, a pressure exercised on any point thereof, is called into action. As the details of the various machines by which the power of water is applied, and the laws connected with its application form part rather of the science of practical mechanical engineering, than of civil hydraulic engineering, the student is referred for them to the Numbers of Mr. Weale's Elementary Series, in which those subjects are particularly discussed.

#### PNEUMATICS.

60. Correctly speaking, the term Pneumatics ought to be confined to the science of the phenomena connected with the atmosphere ; but, by extension, it has also been applied to those connected with all gaseous fluids. The following observations will, however, be confined as much as possible to the phenomena which would be represented by the narrower acceptation of the term, and those of other gaseous fluids will only be alluded to as they may be connected with the atmosphere itself.

61. As was already observed (§ 3.), gaseous fluids differ from aqueous fluids in this important respect : that the former are highly elastic, whilst the latter are so very partially elastic as to warrant the neglect of that property in all reasoning with respect to these fluids. Of the gases themselves, again, there are some which are permanently elastic, and others which, by means of compression, can be converted into liquids. Atmospheric air is an illustration of the compressible, steam of the incompressible, gases ; but Faraday's beautiful researches lead to the belief that this distinction only exists in consequence of our defective means of operating upon them, and that, in reality, all

gases are susceptible of being compressed and condensed when operated upon under favourable conditions. In ordinary language, it is, however, convenient to retain the distinction between the condensible and the incondensable gases, and to apply to the former the name of the *permanent gases*; to the latter, that of *vapours*.

62. The properties common to all gases may be stated as follows: 1, that their elements have weight; 2, that they tend constantly to dilate, in consequence of the repulsive force of their latent caloric exceeding the molecular attraction, and that, therefore, they only retain the same volume from the resistance of some containing body; 3, that they are easily compressible on account of the space around their molecules; 4, that they are elastic, inasmuch as when their molecules are brought into closer connection with one another, the repulsive force of the caloric of the gases increases more rapidly than their molecular attraction; 5, that their molecules are perfectly free to move upon one another; and, 6, that, by reason of their elasticity, a force exercised upon them on one point must be transmitted throughout and in every direction. All these properties have been proved by direct experiment to be possessed by atmospheric air.

63. Since the atmosphere possesses weight, compressibility, elasticity, and the power of communicating pressure in every direction, it follows that any particular portion of it must be pressed by the weight of the atmosphere immediately above the portion under consideration, and must also transmit the effect of this weight to the portions beneath; consequently, the density of the atmosphere, and its elasticity, must decrease as the distance from the earth increases. For the same reasons, every object, or body, placed in the air must be exposed to a pressure upon every part

of its surface, which diminishes with the elevation above the ground.

64. The atmosphere revolves with the earth, and at the same velocity with it; for, if this were not the case, the air at rest would create a resistance to motion equal to the shock it would actually produce if the earth stood still. A current of air, in fact, would be felt, whose velocity would be equal to that of the earth's rotation on its own axis, or, at the circumference, to a velocity of 1518 feet per second; whilst the most violent hurricanes, such as are able to tear up trees and overthrow buildings, do not travel at a rate exceeding 147 feet per second. As the atmosphere thus moves with the earth, all the molecules composing the former are affected by three cosmic forces—gravity, elasticity, and the centrifugal force. Under these circumstances, as the weight and the elastic force of the molecules of the atmosphere diminish in proportion to the distance from the axis of rotation; whilst, on the contrary, the centrifugal force increases with that distance; there must necessarily exist upon any vertical line passing from the centre of the globe a point where these three forces are in equilibrium and the atmosphere must be limited. It has been calculated that the distance at which the atmosphere becomes rarefied to such a degree as to be 760 times lighter than it is at the ordinary level of the earth—a rarefaction equal to that obtained by the best air-pumps—is about 58,000 yards above that level. This is not more than  $\frac{1}{144}$  of the radius of the earth; so that practically it may be considered that the height of the atmosphere above our globe is about equal to  $\frac{1}{100}$  of its radius.

65. If a tube be made air-tight, and filled with any liquid, so as effectually to exclude the air, and then

immersed in a vessel filled by some other liquid whose surface is exposed to the pressure of the atmosphere, it will be found that a column of the first liquid, or of that within the tube, will be sustained in it, and that the height of this column will depend upon the relative specific gravities of the liquids, and be in the inverse ratio of their densities. The force which sustains such a column is produced by the pressure of the atmosphere acting directly upon the exposed surface of the receiving vessel, and pressing it in a downward direction, whilst the liquid in the tube is exposed to no such action; and the effect will be the same, whatever be the section and dimensions of the tube, provided it be not so small as to allow capillary attraction to modify the results. Moreover, the pressure of the atmosphere may be demonstrated to act on every side of the tube or of the receiving vessel; for if the tube be made to assume any direction, the liquid will rise in it to the same height above the surface of the receiving vessel as it would do in a tube held in a perfectly vertical position.

66. As the heights of the liquid columns thus sustained in tubes are precisely in the inverse ratio of the densities of the column, their weights must be exactly equal. Under these circumstances, as it is known that the atmospheric pressure will sustain, on the average, a column of mercury 30 inches in height, it will also sustain a column of water about 34 feet high, since the specific gravity of mercury is 13.56. But as the pressure of the atmosphere varies within such limits as to allow the height of the mercurial column in a tube also to vary 3 inches in height, the height of the water column will also vary to a proportionate extent; that is to say, within a range of about 3 feet 5 inches. The atmosphere itself must exercise



an average pressure of 15 lbs. on the square inch, or the weight of a square vertical prism of atmosphere measuring 1 foot on every side is about 2160 lbs. In works upon Physics, especially in those published abroad, the elastic force of gases is estimated by their relation to the atmospheric pressure, or, as we have seen the latter to be 15 lbs. on the square inch, that quantity becomes the unit of comparison in all such calculations.

67. It is to the pressure of the atmosphere upon the exposed surface of a lower vessel that the ascent of water in a tube from which air has been exhausted is owing. The removal of a certain portion of the air in the tube causes that which remains to expand, its elasticity at the same time diminishes, and the liquid from the lower vessel will rise until the weight of the column thus sustained, and the remaining elasticity and weight of the internal air, shall balance the external pressure. It follows from this law, that, for the same dilatation of the air, the liquid will rise to a height which will be in the inverse ratio of its density.

68. It must be evident, from what has been said above, that the height of a liquid column of any description, in a closed tube, might be taken as the measure of the weight of the atmosphere. But, for the purposes of observation, it has been found to be more convenient to adopt mercury as the standard of comparison, because it admits of the column being made shorter than in the case of any other liquid, on account of its greater specific gravity, and also because it is not so much exposed to give off vapours (whose elasticity would, to a greater or less degree, falsify the indications of the column) as the majority of liquids are liable to do. Even mercury itself gives off vapour; but within the ordinary range of the thermometer in

temperate latitudes, its elasticity is so small that the action of this vapour may be neglected without inconvenience. In the arts, then, we find that almost invariably air-tight tubes in which columns of mercury are free to move according to the pressure of the atmosphere upon the surface of a small cup of mercury in which one of their extremities is immersed, are used to ascertain the pressure of the latter, and are known by the name of Barometers. Of late years the direct pressure of the atmosphere upon a thin metal disc, or diaphragm, covering an air-tight chamber, has been made to indicate the variations in the weight of the atmospheric column, in the elegant and ingenious instrument the Aneroid; and this instrument has been employed for all the purposes connected with engineering to which the barometer itself had previously been devoted. These purposes are for observations upon the weather, and occasionally for ascertaining comparative altitudes; and it is to be observed, that within the range of temperature prevailing in the temperate zones, the use of either the mercurial or the disc barometers may be a matter of indifference. In warm climates, however, the expansion of the disc renders the indications of the aneroid doubtful. As these subjects are more particularly discussed in the Numbers of this Series which treat of Pneumatics and of Mathematical Instruments, the student who might desire further information on the use of the barometer, is referred to them, or to the works cited at the end of this treatise.

69. It is a necessary consequence of that which has been previously stated, that when a gas is compressed, it diminishes in bulk; and as its elasticity increases with its density, it must sooner or later arrive at such a state of condensation that the elastic force of the gas

itself shall balance the pressure exercised; but the laws affecting the condensation and those affecting the elastic force are yet but little known. Practically, and especially in the case of atmospheric air, it may be considered that the pressure exercised by a gas against the sides of a vessel containing it, is increased in precisely the same proportion as the space which it formerly occupied has been diminished; or, in other words, the elastic force of the air, or of any gas, is proportional to its density. It must be observed, however, that a variation in the temperature will affect the elasticity of a gas; for an increase of temperature will give rise to an increase of elasticity without, or even in spite of, any variation in the density.

70. One consequence of the elasticity of gases is, that they exercise a pressure upon their containing vessels independent of any other mechanical or external force; and in this respect they differ from ordinary fluids. The energy of the pressure so exercised depends upon the difference between the elasticities of the contained and of the surrounding gases, independently of any pressure which may be applied to the former.

71. The principles of Pneumatics are applied in the practical operations of hydraulic engineering, in the construction and application of pumps and syphons; and it is therefore necessary to enter into some details of those engines. Pumps are of numerous descriptions, and every maker has his own peculiar fancies with respect to the execution of their parts; but the only really philosophical distinctions between the various kinds of pumps are those founded upon the application or the neglect of the atmospheric pressure; or, the infinite varieties of these machines may be classed under the simple divisions of the *suction* and the *forcing* pump.

72. The ordinary suction pump consists of a *vertical pipe* immersed in water at the lower end ; of a *piston*, moving in an enlarged portion of this pipe, called the *cylinder* or *barrel* ; and of *two clacks* or *valves*, one of which is seated upon the pipe, and the other upon the piston itself. If, in such a pump, of the construction usually adopted, we suppose the piston to be at the bottom of the cylinder, and nearly in contact with the lower valve, upon raising the former the valve upon the piston itself will be closed by the downward pressure of the atmosphere, and a partial vacuum will be formed under the piston. The air in the pipe and barrel of the pump will, therefore, be rarefied, and unable to press upon the surface of the fluid beneath it, with the same force that the atmosphere presses upon the water in the open vase ; and the latter force being no longer balanced, a column of water will be raised in the pipe, whose height will depend upon the atmospheric pressure and the perfection of the vacuum which can be created under the piston. If, further, we suppose the water to rise to a certain height in the pipe, and that the piston then descend to the position it first occupied, the air between it and the water will escape through the valve, and the water will upon the next ascensional movement of the piston again rise in the pipe, until at last the piston actually plunges into it, and the water rising through the valve is retained upon it when it again rises. On this return up-stroke the water above the valve is raised by the piston to the overflow ; a further vacuum is created beneath the piston, and an additional quantity of water from the containing vessel is made to enter the pipe by the atmospheric pressure.

73. The height to be given to such a lifting pipe as we have above described, depends nearly as much upon

the perfection of the vacuum created as upon the atmospheric pressure itself. Instead, then, of being able to raise water by means of suction pumps about 34 feet, as we should be entitled to expect theoretically, it is very rarely that suction pumps can be made to work at greater depths than from 16 to 28 feet; and in all such machines the chances of diminished effect increase with the dimensions of the pump itself. In practice, the usual working depth of a suction pump is made about 24 feet; and the diameters of the suction and ascending pipes are usually made from  $\frac{1}{2}$  to  $\frac{3}{4}$  of the pump-barrel itself. It is necessary, in order to secure the greatest results from these machines, that when the piston descends it should touch the lower clack, so as not to leave any space between the latter and the under side of the piston. The power to be applied to the handle must be in excess of the sum of the weights of the column of water above the piston, and of the column in the ascending pipe, and also be sufficient to overcome the friction of the various parts of the machinery.

74. The forcing pump may be either a species of *lifting* pump, when the column of water is raised directly upon the piston; or strictly a *forcing* pump, when the water is driven by the piston into an ascending pipe. It is usual, in ordinary cases, to combine the suction pump with both these varieties of the forcing pump, in order to make as much use as possible of the atmospheric pressure upon the surface of the water.

75. Evidently any kind of pump, in which the whole weight of a liquid column has to be set in motion at each stroke of the piston, must be so disadvantageous, that it cannot be a matter of surprise that the ordinary lifting pump should be rarely used; nor will it be worth while here to dwell further upon it, than to say,

that this description of engine is really nothing more than the suction pump already described, the upper tube of which has been prolonged. The forcing pump consists of a barrel and suction tube, separated by a clack, opening upwards only into the barrel. The piston, instead of carrying a second clack, is solid, and the clack is placed at the entrance of the ascending pipe, which usually branches off from the barrel in a horizontal direction for a short distance, and then ascends vertically. The motion of the second clack is from the barrel outwards.

76. The action of a pump of this description will be analogous to that of the suction pump until the water rises into the barrel, from the atmospheric pressure; because the piston will rarefy the air beneath it, and the unbalanced pressure upon the containing reservoir, will cause a column of water to rise in the tube. When, however, the water shall have entered the barrel, the piston, upon its next down stroke, will cause the water to force open the foot valve of the ascending pipe, and to rush into the ascending column. The pressure of the water in the latter must act upon its base with a weight proportionate to its height, and if then a motive force be employed in excess of this pressure, the water will continue to be lifted to a height proportional to the assumed motive power.

77. In those suction and forcing pumps, in which the water does not rest upon the piston, the effort necessary to raise the latter is only the weight which would be required to move a weight equal to that of the column of water raised by the suction. But in the act of descending, the piston compresses (to a slight extent) the water, and causes it to flow through the foot valve, and to rise in the ascending column; consequently it requires a power able to set in motion the

whole weight of the latter. There must be evidently a great advantage in equalising these actions, which it is always easy to do, when the total height to which it is required to raise the water does not exceed 56 feet, by merely placing the barrel in the middle of the lift, as the clear difference of level between the upper and lower extremities of the delivery pipes is called. Beyond this height it becomes necessary to adopt mechanical arrangements, in order to communicate greater power to the descending, than to the ascending, stroke of the piston; and it is in such cases that the application of steam power produces some of its most useful and startling results, as exemplified in the large mining, or water-supply engines.

The pistons of forcing pumps were formerly always made of wood, or of metal, packed with leather, so as to work closely against the sides of the barrel; but latterly, the so-called *plunger* pumps have been more generally used. In these pumps the *plunger* is a metallic cylinder, either solid or hollow, of a length a little greater than that of the stroke; the diameter being from  $\frac{1}{2}$  to 1 inch less than the diameter of the barrel. The packing is fixed, and it is indeed formed by the stuffing-box. The plunger, in its descent, takes the place of the water, which it drives before it; and in its ascent it creates a vacuum in the suction pipe, which is immediately filled by the atmospheric pressure upon the water in the lower reservoir.

78. In any pump, therefore, the useful results would be represented by the formula  $Pm = Wh$ , in which we have

$Pm$  = the motive power employed;

$W$  = the weight of the water raised; and

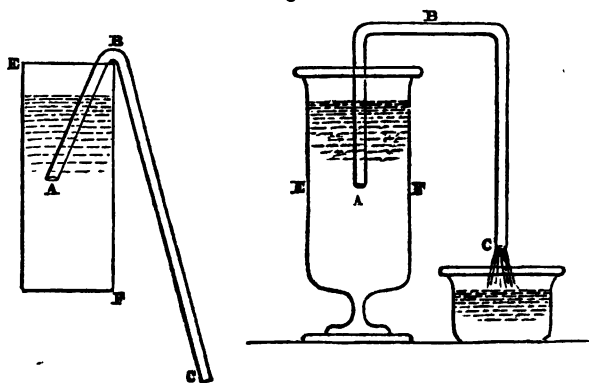
$h$  = the height to which it is so raised above the well.

Practically, however, the useful effect is diminished

by the friction of the packing, of the piston rod, and of the column of water against the sides of the pipe; there is also a loss of power occasioned by the mode of transmission of motion. Moreover, the weight and the friction of the clacks diminish the effective discharging power of the pump; as also must the variations in the direction and velocity of the ascending column, to which must be added, the influence of the velocity of the stream at the point of discharge. In the most perfect descriptions of pumps, it is possible that  $Wh$  may = from  $0.75$  to  $0.80 Pm$ ; but, generally speaking, the coefficient of the useful effect does not exceed, even if it attain so much as,  $0.75$ .

79. Syphons are bent pipes, with legs which are, for the most part, of unequal length; and they are, in the arts, most frequently used for the purpose of transferring liquids from one vase to another, in such wise as to avoid any motion in the liquids of a nature to affect their mechanical purity. The simplest form of the syphon is represented by the annexed sketch

Fig. 8.



(fig. 8), and if, in such a machine, the bent pipe, A, B, C,

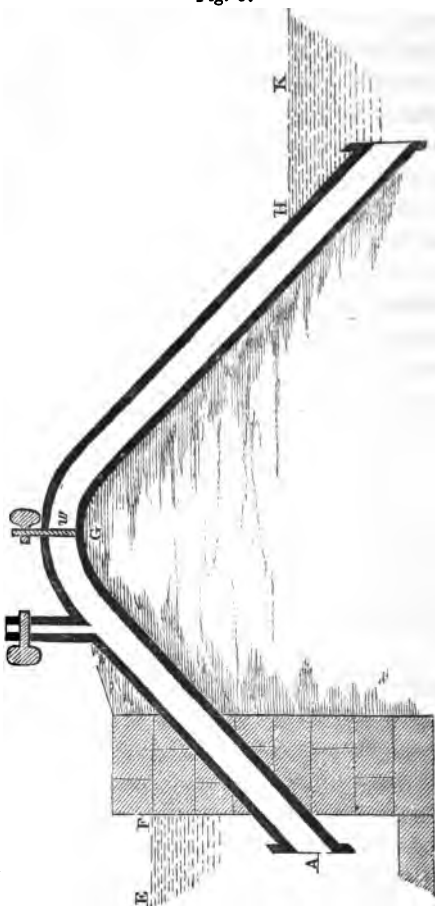


be filled with water, and the short leg,  $A B$ , be inserted in the vase,  $E F$ , the water will be discharged in a continuous stream through  $c$ , if the latter be opened, and the section of the bent tube should not be too great. The rapidity of the discharge will be increased in proportion to the increased difference of level between the surface of the fluid in  $E F$ , and that of the orifice of discharge; or it may become constant, or even cease altogether, when that distance is made to retain a fixed proportion. The theory of the movement of fluids in syphons is very simple; and the practical application of the principles upon which it was founded, as usual, preceded the clear recognition of the principles themselves; for the ancient Egyptians and the Romans appear to have habitually employed this class of machinery in the ordinary transactions of business, if we may judge by the pictorial representations which have been preserved. It was reserved however, to Pascal to discover the laws which affect the detailed action of syphons. It is to this author then that we owe the authoritative announcement of the laws, briefly sketched in the following paragraphs.

80. As the pressure of the atmosphere on a water surface is able to support a column of about 33 or 34 feet high in a hollow tube, wherein a vacuum has been made in the upper part, if we suppose that a small partition  $w$  be placed in  $G$ , or the highest portion of the syphon (fig. 9), the column between  $G$  and  $E F$  will not only be sustained, but it will be pressed against the partition  $w$  with a force equal to the weight of a similar column, having a base,  $w$ , and a height of from 33 to 34 feet, minus the difference of level between the surface  $E F$  and the partition  $w$ . But when the syphon is filled with a fluid, the opposite side of the partition  $w$  is acted upon by a column of the same transverse

dimensions as before, having, however, the height of 33 or 34 feet, minus the difference of level between  $w$  and the surface,  $HK$ , of the lower or receiving vase; this pressure, consequently, is less than the first. It follows, therefore, that if the partition  $w$  were moveable, or, to return to the actual conditions of syphons, if there were no such partition, that the liquid section at the highest point would be urged in the direction  $A, G, H$ , by a force equal to the difference between the levels of the liquids in the upper or lower vessels thus put in communication with one another.

Fig. 9.



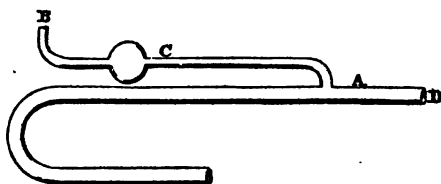
81. In the above reasoning it is supposed that the pressures exercised in the interior of the syphon upon the levels of the respective vessels are equal,

and of the same character ; but this would not be so decidedly the case if the syphon and the vessels were immersed in a liquid able to exercise a pressure upon the exposed surfaces of the reservoirs, such as to counteract appreciably that of the column producing motion. Thus, for instance, if the vases were filled with mercury and immersed in water, the pressures upon their surfaces would be very different, and the excess of the first over the second would equal that produced by a column of water equal to the difference between the levels of those surfaces. This excess of pressure, which acts to raise the mercury in the longer leg of the syphon, would immediately retard the flow ; and the pressure, which will really produce the movement of the liquid, would only be equal to the difference of the weights of two columns of mercury and water having the same bases and lengths, equal to those of the respective branches measured between the surfaces of the vessels. A very curious fact results from this law ; namely, that if the liquid exterior to the syphon were denser than that in the interior, the direction of the flow would be reversed, or that it would take place from the longer to the shorter leg of the syphon. This phenomenon is rarely exhibited in the transmission of liquids ; but it may be observed to take place in the movements of heated gases in chimneys, or in artificial ventilation.

82. In using syphons the ordinary course is to fill the instrument with the liquid to be transferred, either by pouring a sufficient quantity into the tube, or by exhausting the air in the longer leg, which leaves the pressure upon the surface of the upper vessel unbalanced ; and therefore allows the liquid to rise over the summit of the syphon. The ordinary form of the syphons used in the arts, or for philosophical experiments, is that represented by fig. 10, in which a lateral

tube, C, B, A, is soldered to the side of the longer leg, and has a small bulb at the point c. When this

Fig. 10.



instrument is used, the extremity, D, is closed, and the air is exhausted from the interior, the exhaustion is known to be completed by the arrival of the liquid at D; if D be then opened, the liquid will continue to flow through it; but it must be observed, that inasmuch as the longer leg communicates with the air at c, the effective pressure is limited by the height of the latter. When large syphons are used, as in the case of waterworks, or embankments against the sea, it is necessary to have their two extremities immersed; for otherwise the air would enter and accumulate in the longer leg to such an extent as to cut off the column. To set these large syphons at work, it is usual to exhaust the air they may contain, and then to fill them by means of a small pump placed near their summits; when the liquid rises up to the pump itself, its clack is fastened down, the bottom valve of the syphon is opened, and the passage of the fluid commences. A very good description of the syphons used in the Don Reservoirs, by Mr. R. Mallett, will be found in Weale's "Quarterly Papers on Engineering, 1847;" and in Borgnis' "Traité des Machines, vol. 3, Paris, 1819," will be found some useful information upon the subjects of both pumps and syphons.

83. Several machines, whose actions depend upon

the application of the laws of pneumatics, are used occasionally in hydraulic engineering, such as the diving bell, camels, floating docks, &c.; but their details belong so much more especially to the other branches of practical mechanics, that it may suffice merely to allude to them at present, or to describe some of the more important of them incidentally in subsequent parts of this work. The application of the motive power of wind to land drainage is, however, often of so great importance, that it seems advisable to dwell upon it somewhat more in detail than it is proposed to do with respect to the class of machinery just mentioned.

84. Smeaton, in a paper communicated to the Royal Society 1757, drew up the following table of the velocity, and the perpendicular force of the wind under different circumstances.

TABLE IV.

Miles per Hour.	Feet per Second.	Perpendicular Force on One Square Foot in Avoirdupois Pounds and Parts.
1	1.47	0.005
2	2.93	0.020
3	4.4	0.044
4	5.87	0.079
5	7.33	0.123
10	14.67	0.492
15	22.00	1.107
20	29.34	1.968
25	36.67	3.075
30	44.01	4.429
35	51.34	6.027
40	58.68	7.873
45	66.01	9.963
50	73.35	12.300
60	88.02	17.715
80	117.36	31.490
100	146.7	49.200

It has been found, practically, that a wind moving with a velocity of less than ten miles per hour is not

able to insure the working of a corn mill; when the velocity exceeds twenty miles per hour it is necessary to furl the sails. A wind travelling with the last-named velocity is, however, considered to be the most suitable for the purposes of navigation.

85. According to Smeaton also, a windmill yields the greatest effect when its sails are made with concave surfaces of a rather complex form, the generating lines of which, situated at points obtained by dividing the length of the sail into six equal parts, form with the axis of the shaft, or the direction of the plane of movement of the sails, the angles indicated in the following table. (The generating line No. 1 is that which is nearest to the axis, and it is at this point that the sail begins.) Usually the width of the sail varies between  $\frac{1}{3}$  and  $\frac{1}{4}$  of the length; and, in the best mills it never exceeds  $\frac{1}{4}$  of that dimension.

TABLE V.

No. of generating Line.	Angle with Axis.	Angle with Plane of Movement of the Sails.	Observations.
1	72°00	18°00	The angles of the third column are the complements of those in the second.
2	71°00	19°00	
3 middle	72°00	18°00	
4	74°00	16°00	
5	77°50	12°50	
6	83°00	7°00	

86. From the same authority it would appear that when the sails of a mill are well filled, the velocity of their extremities, without a load, is equal to four times the velocity of the wind; and that it is necessary that the velocity of the extremities, with a load, should be

2·5 or 2·7 the velocity of the wind, in order to obtain the maximum useful effect. These same useful effects produced, are found to be in the ratio of the cubes of the velocity of the wind, and they may be represented by the formula  $P = \frac{v^3 a^2 \sin^3 \theta}{440}$ , in which  $P$  represents the impulse in pounds avoirdupois;  $v$ , the velocity of the wind in feet per second;  $a^2$ , the area of the sail in feet; and  $\theta$ , the angle to the direction of the current. Claudel gives a very simple and a very useful formula for estimating the power exerted upon a plane surface, normal to the direction of the movement of the wind, which may be usefully quoted here; it is the one in which

$$P = ds \times 2h, \text{ wherein}$$

$P$  represents the pressure in lbs. per foot superficial;  $d$ , the weight of a foot cube of the air in movement;  $s$ , the surface of the plane receiving the shock, measured in feet superficial; and  $h$ , the height producing the velocity, or  $h = \frac{v^2}{2g}$  according to the usual formula upon the subject. In this case it is supposed that the barometric pressure is equal to 30 inches of the mercurial column, and that the temperature is equal to 53·6; under which conditions  $d$  would equal 2·71 lbs. avoirdupois.

87. In Holland windmills are extensively used for the purposes of drainage; and it is the practice in that country to employ one mill, with sweeps of from 80 to 90 feet in diameter, for every 1250 acres drained, provided the lift do not exceed 5 feet. These mills are considered to work upon the average 60 days in the year, and to raise an effective total quantity of water equivalent to 695,220,000 cubic feet of water lifted 1 foot vertical. But it must be observed that the

Dutch "Windwatermoelen" are very far indeed from yielding the maximum working effect they might produce if they were built upon the more modern and certainly more approved plans. It is extremely rare to see a mill which "winds" itself; and still more rare is it to see the sails of a mill provided with self-regulating wooden blades, instead of canvas sails, which must be furled by hand or be blown to rags if an unexpected storm should arise. In England it has been found to be, on the whole, more economical to employ steam power than to use the motive power of the wind for the purposes of drainage, as we shall have occasion hereafter to mention in the chapter of this work, especially devoted to the consideration of this question. Where coal is dear, and iron is expensive, windmills will always be of the greatest value for engineering purposes; and it is, therefore, much to be regretted that this class of engines should have been so systematically neglected as it has been of late years, especially by English engineers.

88. Coulomb observed, we may here add, that the total annual work of a windmill was only  $\frac{1}{3}$  of the effective power which such a machine would be able to produce by working continuously under the most favourable circumstances. This calculation is very far in excess of those of the Dutch water engineers; and the experiments of both Hachette and d'Aubuisson, show that Coulomb was certainly deceived in the matter. It is but fair to observe that the class of water raising machinery, to which the Dutch windmills are generally applied, is of the rudest and most incomplete description of "dash wheel," as it is called; and that really, in any machine of this particular description, the simplicity of its construction and the facility of its repairs are often of much greater importance than the



attainment of the maximum dynamical effect from the motive power employed. •

89. There are many other phenomena connected with the science of pneumatics of great interest to the engineer and to the public in general; such as those connected with the movement of gases in pipes, aërostation, sound and its transmission, evaporation, distillation, crystallisation, &c.; to some of which it will be necessary to refer hereafter in the consideration of the practical details of the comprehensive science of hydraulic engineering. In the meantime, if the reader should require, at once, further information upon the numerous subjects thus alluded to, he is referred to the other Treatises in this series, especially to those upon hydraulics, pneumatics, rivers, &c., and to the list of authors to be found in the Appendix to the present work.

#### APPLIED CHEMISTRY.

90. The conditions under which the various building materials decay have so great an influence upon the stability of the structures erected by the hydraulic engineer, that their investigation ought always to command attention. There is much obscurity, however, with respect to the practical application of the great principles of chemical science to building purposes; and the various actions and reactions produced by the materials used, or by the external agent to which they are exposed, have not yet been studied in any consecutive or philosophical spirit. The following remarks must, therefore, be considered rather as an attempt to collect and record the little which is actually known upon the subject, than as a statement of a body of scientific principles. It would perhaps be convenient for the purposes of investigation to discuss the

condition of the chemical actions observable in building materials, 1, in air, and 2, in water; but these actions are often so intermingled that any such subclassification can only be partially observed.

91. Of course all these materials are perceptibly affected by the changes of volume produced by variations of temperature, and in designing any important building of the class now under consideration it is absolutely necessary to take into account the probable effect of the dilation consequent upon an increase of that description. Extreme cold, however, exercises a more marked influence upon the mechanical structure of building materials than the ordinary degrees of heat are able to do; and this influence is itself the greater in proportion to the amount of water which may be present in the pores of the material. It is indeed principally on account of the change of volume produced by the passage of the contained water from the liquid to the solid state during congelation, that disintegration ensues; and it therefore follows, that up to a certain point, and under certain conditions, the facility with which any substance absorbs water may be considered to be an indication of its tendency to decay under the influence of extreme cold. There appear, however, to be several very marked exceptions to this rule, at present inexplicable; for some of the more commonly used descriptions of building stone absorb water freely, but do not yield easily to the effect of cold; and in the case of the distinctly marked bedding of the Yorkshire paving, it rarely happens that the water which may exist between the layers causes these to separate upon the occurrence of frost. The various metals are often seriously affected by extreme cold, and this influence extends not only to their change of volume, but also to the modifications of their other

physical characteristics; for instance, some of the metals become in times of frost extremely brittle, or they lose in fact much of their malleability. Iron is especially liable to this action, cast iron even more so than wrought; and it would appear that there is some kind of inverse relation, hitherto not clearly ascertained, between the rates of fusion of the different metals, and their susceptibility of change in their conditions of malleability under the action of extreme cold. Woods vary less in volume with changes in the atmospheric temperature than the other building materials, especially when they have previously lost their sap; but even they are not exempt from the action in question, and it has been observed that a species of torsion of the fibres takes place in wood when directly exposed to the sun's rays, and that the fibres slowly and imperfectly follow their path. The influence of frost upon the cohesion of building materials becomes of the most serious importance in cases wherein machinery of any description is employed; and it is therefore impossible for the hydraulic engineer to exaggerate its importance. The rupture of chain cables, tie-rods, bollards, &c., when exposed to sudden shocks during hard winters, is of sufficiently frequent recurrence to justify the short notice thus given of its danger.

92. The chemical actions which take place in building materials are, however, even more injurious than the very decidedly mechanical ones thus alluded to; but they are similarly affected by the conditions of temperature; and as they depend upon the reciprocal influences of the atmosphere, and of the elementary substances of the materials in question, it may be desirable, first, to notice in general terms the composition of the atmosphere, and then to examine briefly the changes it is able to produce: the composition and

action of sea water will be noticed incidentally. In its normal state, the atmosphere is considered to be composed of oxygen and nitrogen, in the proportions of 208 of the former to 792 of the latter; but it also contains, in variable proportions, dependent upon local causes, numerous other gases, such as carbonic acid, ammoniacal, hydrochloric, nitrous, sulphurous, and sulphuretted hydrogen gases; and it is important to observe, that the relative proportion of these gases varies in the same locality with the elevation above the ground. Messrs. Boussingault and Lévy ascertained that the quantity of carbonic acid gas present in the atmosphere of Paris was 3·253 parts in 10,000, whilst at Andilly it was only 2·989; but Lévy himself considers the proportion of this gas usually to vary between the limits of from 4 to 6 parts in 10,000. Carburetted hydrogen is found most abundantly in the neighbourhood of marshes; nitrous acid gas in districts which are subject to violent storms. Frésenius states that the quantity of ammonia (in various forms, such as the oxide and carbonate) usually to be found in the air, is about 0·677 in 100,000; a quantity Boussingault's observations would lead us to believe to be less than the one which really obtains, for he found that the ammonia in rain water varied from 1 to 5·45 in 100,000, and that the proportion depended mainly upon the position of the place where the water was collected. Under any circumstances, it appears that the night air contains more ammonia than that of the day; that of towns contains more than the air of country districts; and from the observations of M. Chevalier, it would appear that other forms of ammonia (the acetate and hydrosulphate) are often to be discovered in notable proportions in the air of towns. Vogel ascertained that the air of the shores of the

Mediterranean and of the Baltic contained a certain proportion of hydrochloric acid ; and there seems to be every reason to believe that the same fact must exist in other localities of the same description, dependent of course upon the rate and conditions of evaporation there prevailing. Many other gases must, no doubt, be present in the atmosphere, though from their extremely minute proportions, it is difficult to ascertain their precise influence, or even their existence, in some cases.

98. The meteorological conditions of the atmosphere are subject to periodical variations, and they have distinctly marked phases of nocturnal and diurnal energy, unless any extraordinary circumstances should occur to modify their action. Thus, in clear weather the atmosphere attains two maxima and minima in its electrical state ; the first maximum occurring between seven and nine in the morning, and the second between seven and nine in the evening ; the first minimum about four in the morning, and the second between five and ten in the evening ; but it must be observed that the hygrometric state of the atmosphere frequently modifies the above cited periods. The intensity of the sun's light, and, therefore, necessarily that of its actinic influence, has its maximum rather before midday, and it has two minima corresponding nearly with twilight. A maximum occurs in the temperature about two o'clock in the afternoon, on the average of the year, but there is a slight irregularity according to the seasons ; a minimum occurs, according to M. Bouvard's observations carried on in Paris, when the sun, in the early part of the day, occupies a position of about  $14^{\circ} 17'$  below the horizon ; the period of the diurnal mean temperature varies in the different months of the year. It is about midday that the atmosphere is generally in

its driest state, and about midnight it contains the greatest quantity of moisture; whilst it is between midnight and sun-rise that the greatest deposition of dew takes place, on account of the greater degree of cold we have already seen to prevail about that part of the day. In our particular (northern) localities the disturbances of the barometric action are not characterised by any regularity; but, as a general rule, there appears to be a tendency in the atmosphere to increase in pressure in the morning, for the mercury in the barometer then generally rises; it falls about midday; rises again about sunset; and falls once more about midnight. In fact, however, it may be considered that the fluctuations in the meteorological conditions of the atmosphere are affected by the relative positions of the sun and of the earth; and that they rudely correspond with the cardinal positions of the former of those bodies, at its so-called rising and setting, and at mid-day and midnight. In London itself, the mean temperature throughout the year is  $50^{\circ} 50'$ , whilst that of the adjacent country districts is  $48^{\circ} 50'$ . The thermometer in that town very rarely rises about  $96^{\circ}$ , and the greatest cold recorded has never descended below  $5^{\circ}$  under zero of Fahrenheit's scale. The mean range of the barometric pressure does not exceed 2.07 inches.

94. One of the most important conditions of the atmospheric action upon building materials is that one connected with the rate of evaporation, and the amount of humidity in suspension; and the intensity of these respective phases of the hygrometric influence is the greatest at precisely opposite seasons of the year. That is to say: evaporation is the most active in the summer, and the least active in the winter months; whilst the opposite law prevails with respect to the

amount of moisture in suspension in the atmosphere. Thus, Mr. Daniel estimated the total mean evaporation in the neighbourhood of London at 23·974 inches per annum, ranging in the various months of the year from about half an inch in January and December, to  $3\frac{1}{4}$  inches in June, and  $3\frac{1}{4}$  inches in July; and, assuming the complete saturation of the atmosphere with humidity to be represented by 100, that of the months of December, January, and February will be expressed by 92. In the intervening months the humidity diminishes with tolerable regularity to a minimum of 78 at the end of June, excepting that a trifling irregularity occurs in the month of May. It thence appears that the greatest amount of moisture is suspended in the atmosphere precisely at the period when the temperature is the lowest, and when frost is the most likely to affect the moisture which might be absorbed by the porous building materials; whilst, on the other hand, evaporation takes place with the greatest energy at the period when the conditions of temperature would be most favourable to the production and development of the salts generated by the action of the absorbed moisture upon the earthy bases of those materials, which salts are either themselves actively destructive, or from the fact of their solubility or of their deliquescence, facilitate the decomposition of the various metals, stones, or timbers.

95. The conditions under which mineral substances have crystallised appear to exercise a great and hitherto unexplained influence upon their powers of resistance to external agents; and it would also appear that it is a matter of great importance to have the original crystallisation undisturbed. Thus, in the cases of the various descriptions of silica usually dealt with by the hydraulic engineer, we find that the

decidedly characterised form of the "quartz" is able to resist any ordinary amounts of heat and nearly all chemical actions, but that flint, an imperfectly or amorphously formed crystallisation of silica, is susceptible of decomposition in caustic alkalis under high pressure; and that the silica beds of the subcretaceous group can be reduced with comparative ease to the gelatinous form without pressure. Again, the amorphous limestones, such as the common chalk, are soluble in water with comparative ease; but the more decidedly crystallised oolites, or any of the more dense and more regularly formed stones or marbles, resist the solvent action of that element in a very marked manner. But all forms of crystallisation are not thus permanent, and there is, for instance, a large class of materials used in building—the sulphates of lime—which slowly dissolve under the action even of the moisture in suspension in the atmosphere. Any mechanical interference with the crystals of the various bodies under consideration has a decided influence upon their durability, not only because it destroys the coherence of the mass, but because it leaves the separate molecules more exposed to the attacks of external agents. It is for these reasons that it is undesirable to attempt to alter the forms of metals after they have once crystallised in cooling; nor can the practical results obtained by the lamination of iron, lead, or zinc be considered to invalidate this opinion; because, first, those metals possess rather more of a fibrous than of a distinctly crystalline character, and secondly, there is reason to believe that a fresh arrangement of the crystals actually takes place under the influence of the various actions developed during, or by the composition. In the case of the cast, and subsequently rolled glasses, the effects of



the subsequent interferences above alluded to may often be distinctly observed.

96. The hydraulic engineer, however, is most directly interested in the study of the influence of the laws of crystallisation upon the resistance of such materials as bricks, and limes and cements, which enter so largely into the constructions he is employed to direct. It would appear, in these cases, that the durability of the silicates, whether simple or compound, depends mainly upon the facts of their gradual formation, if obtained solely in the humid way, or of their formation under the influence of intense heat, if obtained by any rapid process. It is for this reason that the powers of bricks to resist decay depend mainly upon the degree of burning to which they have been exposed. Of course this degree must vary with the composition of the clay of which the bricks are made, and it would be the least in those clays containing bases able easily to form crystalline double silicates in combination with the alumina; but it is notorious, that the underburnt pulverulent bricks, or those in which no indications of a rude crystallisation can be observed, rapidly decay in damp positions, although even there they may serve one good purpose, to be noticed hereafter; whilst the dense, semi-vitreous, and crystalline texture of the harder burnt bricks enables them to resist external agencies. In the phenomena connected with the solidification of some limes the facts above mentioned are perhaps even more distinctly observable; for it is now established with tolerable certainty, that limes and cements only resist the dissolving action of sea-water when they have previously given rise to the formation of a subcrystalline double silicate of lime and alumina, or of lime and magnesia. This double silicate is formed slowly in cases wherein

the lime is obtained from the argillaceous limestones containing small doses of alumina, more rapidly in those wherein the clay exists in larger proportions in the stone ; but in neither of these cases do the resulting cementitious materials attain the ultimate hardness or powers of resistance which they do when obtained from a mixture of the proper proportions of chalk and clay (carbonate of lime and silicate of alumina) burnt at so high a temperature as to produce the commencement of vitrification. It is upon this principle that the Portland cement may be considered to be so much superior to other materials of the same description ; and it is upon the principle of the slow formation of the silicate of lime and alumina in the humid way, that we may explain the useful action of the soft bricks alluded to above. The alumina is, in fact, gradually taken up by the lime, or a portion of the lime passes into combination with the alumina of the bricks, by a species of interchange when such materials are constantly exposed to water ; in workmen's phrase, they thus become "water bound." But alike whether the combination take place slowly or rapidly, whether it take place in the dry or in the humid way, neither the simple nor the double silicates can be resistant to external meteorological agents unless they have assumed a commencement of crystallisation, and the more perfectly that action has taken place the more permanent will be the resulting substance.

97. Of the natural building materials, so to speak, usually employed, a very large and important class—viz., those containing much felspar, such as the plutonic rocks, or the granites, porphyries, whinstones, or basalts—yield to the ordinary action of the atmosphere in variable degrees, according to the composition of the felspar itself and to the conditions of their

crystalline arrangement. It may be that the greater compactness of some of these materials influences their resistance, and that their homogeneity, or their mixed structure, may likewise have some effect; for, evidently, the more open-grained or porous materials must absorb greater quantities of water than the denser ones, and they must, consequently, be more likely to be affected by the changes of form of the water itself: and it must equally be evident that the different rates of expansion of the elementary substances which enter into the composition of the various compound bodies must tend to disintegrate the latter, if those rates be allowed to operate in their most extreme degrees. The decay of these materials, then, may be considered to be as much mechanical as it is chemical; and a safe rule may be established as to their use, namely, that those should be preferred which, *sui generis*, have the smallest grain, the most regular crystallisation, and the simplest composition; the mere specific gravity of the plutonic materials is in itself nearly an infallible criterion of their powers of resistance to meteorological agencies. The same remarks may be extended to the slate rocks, for their durability mainly depends upon their density and the even texture of their mass.

98. In the sandstones and conglomerates, decay may proceed from either the decomposition of the cementing materials, or from the mechanical disintegration resulting from the unequal contractions produced by changes in the state or temperature of the atmosphere. If, for instance, the cementing material should be a limestone, or even a clay, it may often be soluble in water frequently renewed, especially when that water contains any appreciable proportion of carbonic acid gas, as is almost always the case in rain water. Or again, if the cementitious material should be simply of a different

capacity for heat to that of the substances united, or if they should principally be disposed in layers between the principal ingredients of the mass; frost will be very likely to cause them to disintegrate. It is thus that stones, such as the Bramley Fall, in which the cementitious material to the large grains of silica is itself nearly a pure silica, resist external causes of decay with remarkable energy. Whilst, on the other hand, some of the Yorkshire stones, those in which the layers of agglutinated sand are occasionally separated by means of thin sheets of clay, are markedly exposed to decay from the fact of the filtration of water between the various beds. It is, however, important to observe, that the decay which actually arises with these materials does not affect the silica, or their main element, so much as it does the cementing material, or the adventitious substances entering into their composition. With limestones, however, this ceases to be true, for both the carbonates of lime (whether argillaceous or not) and the magnesian limestones, are more or less easily soluble in pure water, or in water containing small doses of carbonic acid. It may, therefore, be considered that the hydraulic engineer should avoid, as far as possible, the use of building materials of this description under water; and if from local considerations of economy he should not be able to use the siliceous stones of a dense, uniform, and crystalline nature, he must be careful in selecting such limestones as are likely, from the conditions of their structure, to resist the action of the element to which they are exposed, or, in other words, to select the densest, most uniform, and most crystalline varieties of limestone.

99. When permeable building materials are exposed to alternations of wetness and dryness, or are used

upon the limits of their capillary action on the moisture of the ground, a chemical effect of a more complicated nature than either of those hitherto considered begins to take place. In proportion to the permeability of these materials themselves new salts are formed, by the decomposition of the original elements under the influence of the water, and of the gases which permeate their various substances. Not only does this action cause the bodies exposed to it to decay, on account of the chemical changes it superinduces, but the efflorescence of the salts thus formed tends to destroy the substances in which they are formed by the mechanical force developed in the process of their crystallisation. The generally received opinion on the subject of the formation of these salts is that they consist of the nitrate of soda—the saltpetre of commerce—or of the nitrate of lime, and that the nitrogen is furnished by the decomposition of the animal matter which is diffused through all stratified deposits. Dumas states that azote and oxygen combine most readily under the influence of electricity; but that the energetic bases, such as lime and magnesia, may suffice, especially when water is present, to replace that intermediate agent. However the formation of saltpetre upon building stones be explained, it is certain that it is produced in the greatest abundance in the zone of the alternations of dryness and humidity; and it may be observed that building materials decay, from this cause, much more rapidly when they are exposed to the action of tides, or at a small height from the ground, than they do under water, or immediately in contact with damp earth. It is, therefore, necessary to use, in positions exposed to the alternations above referred to, only such materials as are of a dense, uniform character, and are composed of elements

insoluble in water. Ordinary carbonates and magnesian carbonates of lime should not be used in these positions; but wherever it is possible so to do, the crystalline, or conglomerate, silica rocks should be employed, for they resist the chemical actions of gases quite as effectually as they resist the solvent action of water.

100. Wood when employed in works connected with hydraulic engineering is exposed to several special causes of decay, arising from the peculiar series of changes which take place in its elements under the influence of the organic substances it contains. The decomposition and fermentation of the sap, and the apparently spontaneous development of fungoid bodies, are amongst the most striking illustrations of these changes; but in addition to them, wood is of course exposed to the ordinary laws of inert chemistry, so to speak. The danger arising from the first cited causes of decay may almost entirely be obviated by observing the simple precaution of not placing the wood in a building until the whole of the sap has been withdrawn, and of maintaining something like a circulation of air round the portions buried in walls, if some portions should be thus buried, and others exposed to the air; for it is to be observed that woods which are constantly covered, either by earth or by water, do not decay in the same manner as those which are partially exposed. It is impossible at present to explain the reasons for the different resistances of woods, even under precisely similar circumstances; but it is essential for the hydraulic engineer to observe that such woods as oak and fir resist more effectually alternations of wet and dry, or, to use the workman's phrase, "last better between wind and water," than beech, ash, or elm; but that elm lasts for a very long time if kept constantly under water, and that beech

piles are even more durable than fir ones in damp ground, when the air can have no access to them. In either of the cases thus named there is no reason to fear the kind of decay resulting from the fermentation of the sap; for this action appears to require the presence of warm damp air, rather than the existence of constant moisture; and it is for this reason that freshly cut timber may be used in pile foundations which are not exposed to changes in their conditions of humidity, whilst it is indispensable to employ in the open air, or in exposed positions, properly seasoned wood, free from sap. When wood is only exposed to ordinary atmospheric changes, its preservation may, to a great extent, be secured by filling in the pores of the exposed surface with paint, or any other material of a nature to prevent moisture from penetrating to the interior; but it is essential, even in such cases, that the sap should be entirely removed before the external pores are closed, or the subsequent fermentation which will take place in it, will produce a peculiar decomposition of the woody fibre known amongst practical builders by the term, "wet rot." The "dry rot" is a species of fungoid growth, considered to be extremely destructive to wood; but perhaps it would be more philosophical to say that the fungoid growth in question develops itself in the most distinct manner under the circumstances which are most injurious to wood, that is to say, in confined, stagnant, warm, damp air.

101. Metals when exposed to the atmosphere are liable to decay, not only on account of the new compounds they form with the gases therein present, but also on account of the electro-chemical changes they undergo. As the number of metals used in ordinary building operations is confined practically to a very few, such as iron, lead, copper, tin, zinc, and the mixed

metals brass, or bronze, it may suffice to notice briefly the phenomena to which their exposure gives rise under ordinary circumstances.

*a.* Iron decays, or rusts, by the formation of a hydrous oxide of that metal, which is soluble in water frequently renewed, or which detaches itself in scales in the open air. When carbonic acid gas is present, the decay takes place with great rapidity, and it is even considered by some authorities that the presence of that gas is absolutely necessary for its development. Reasoning upon this supposition, M. Vicat and the French engineers adopted the system of surrounding the iron work they were obliged to bed in masonry with a hydrate of rich lime, believing that the latter would, on account of its great affinity for carbonic acid, prevent that gas from acting upon the iron. To a certain extent this reasoning is correct, but it is impracticable to keep the hydrate of lime in such immediate contact with the iron as to prevent the passage of moisture between the two substances, and the sad failure of the Suspension Bridge at Angers, in consequence of the rusting of the cables supposed to have been protected by their immersion in the hydrate of lime, may be referred to as an illustration of the danger of the system. It is usually considered that waters containing in solution small quantities of earthy salts act less injuriously upon iron than purer waters would do; and M. Payen ascertained, by direct experiment, that the addition of very small quantities of the sub-carbonate of potassa or of sodium to pure water, rendered the latter innocuous to either cast or wrought iron, and that the same preservative effect was to be observed in all alkaline solutions. On the contrary, however, he found that the addition of a small quantity of the chloride of sodium accelerated the ordinary



rate of oxidation. It appears that grey cast iron is more susceptible of rusting than either wrought iron, or white cast iron; and that the wrought metal resists the action of sea water better than the cast. When iron is exposed to frequent shocks, or vibratory movements, it is less affected by rust than when it remains constantly in one place without such disturbance; but the positions in which iron decays the most rapidly are those where it is fixed, and is alternately exposed to the air, or immersed in sea water. Ammoniacal and sulphuric acid gases exercise very serious effects upon the durability of iron.

b. Zinc when exposed to the atmosphere in its ordinary state rapidly combines with the carbonic acid contained therein, and gives rise to a whitish efflorescence adhering to the material and constituting, as it were, a protective varnish. When, however, any sulphuric or hydrochloric acid is present, as on the sea shore, or in towns like London, where much coal is burnt, various other compounds of a soluble nature are formed. In sea water naturally these compounds are formed more rapidly than in the air.

c. Copper resists external destructive agencies in a very remarkable manner; and many of the gases above enumerated, which are so injurious to other substances, are without effect upon it. Upon exposure to the air a film of either the oxide or the carbonate of copper is formed over the surface of the metal, and it effectually protects the latter against subsequent attack. Formerly copper was likewise considered to be able to resist the action of sea water better than any other metal could do; but of late years it has been asserted that a mixed metal, or species of bronze made of copper and zinc, resisted both the atmosphere and sea water more successfully than pure copper alone.

d. Lead undergoes little change upon exposure either to air or water, especially when the latter contains any of the salts of lime. Brande, however, makes the very important observation, that when lead is kept in distilled water to which air has access, small crystalline scales of the oxide of lead are formed, a portion of which dissolves in the water and is again slowly precipitated in the form of a carbonate. As the very pure, soft waters are nearly analogous to distilled water in their chemical composition, the same actions must take place with them; and it is notorious that they produce very distinct effects upon the lead to which they have access. The use of lead for cisterns must, therefore, be regulated by the nature of the water to be preserved in them; but there does not appear to be any reason why lead should not be applied in every district for ordinary purposes of construction.

102. A very curious, and a highly important, effect is observed to take place when two metals are placed in contact with one another, and when moisture has access to them. A species of galvanic action takes place, which causes one, or sometimes both of the metals to decay with great rapidity; and this may be observed to be the case whether the moisture contain carbonic acid or not, although it is most perceptible when that gas is present. Thus the feet of iron railings when run with lead into stone, or iron cramps, tie-rods, sockets, &c., run with lead into the masonry of locks or other hydraulic works, decay very rapidly, and the more so, in proportion to the purity and the malleability of the iron itself. A similar phenomenon may be observed to take place when iron is in contact with bronze, or with copper, in sea water; but, in this case, although the iron decays rapidly, it would appear to exercise a preservative influence upon the copper.

The preservative electrical action thus developed is not by any means confined to iron and copper, but it would appear generally to take place when two metals are in contact, and are immersed in a solution of any alkaline salts. Thus it is that zinc, tin, and iron, protect copper in sea water; that zinc protects iron and tin, but is itself rapidly corroded if used in sea water in contact with iron; that tinned iron decays unequally in that element, the iron oxidating rapidly, whilst the tin remains intact; and, indeed, the destruction of iron seems to take place more rapidly when that metal is in contact with tin than when it is in contact with copper. When waters contain much of the bicarbonate of lime, that substance is often deposited upon the soldered joints of the pipes through which it may pass, in consequence of a decomposition produced by the galvanic action of the metal of the pipes, and of the joints. It will be necessary to revert to this subject hereafter, in the portion of this work devoted to the consideration of the distribution of water to towns.

103. Mr. Robert Mallet has made many valuable experiments for the purpose of discovering some method for preserving iron from rusting, which have been recorded in the "Transactions" of the British Association for the Advancement of Science. From these experiments, it would appear that a coating of gas tar, applied hot, is the most efficacious protection to iron-work exposed to cold water, and that a coating of caoutchouc varnish is preferable when the iron is exposed to hot water; but that neither of them can be considered to be a durable defence. The process of coating iron with zinc, or galvanising it, is considered by some persons to be the surest mode of protecting the former metal; if, however, the protecting coat should be chipped or scaled off, the decay of the portions thus

exposed would take place with even greater rapidity than it would have done if no attempt had been made to guard against the danger ; because, really, a galvanic action then "sets up," and facilitates the oxidation of the iron. So long, in fact, as the iron is covered it is in an electro-negative state, and it is known that during the existence of this state there is little tendency on the part of the iron to combine with oxygen ; but this ceases to be the case when the iron is uncovered, for it is then free to assume any electrical state which may be superinduced by the atmospheric or other conditions around it, and then to decay as usual.

104. In the preceding remarks no particular attention has been directed to the composition of sea water, but the chemical actions it produces are sufficiently important to justify a cursory allusion to the subject, and at the same time to justify the reference of the student to the authors who have treated the subject in greater detail than would be consistent with the limits of this treatise. Sea water, then, has a specific gravity of 1.026 or of 1.028 ; and its freezing point is usually about  $28.5^{\circ}$ . Formerly it was considered that its composition did not vary much, from whatever latitude or longitude it was obtained, provided only that the depth from which the sample was taken was sufficiently great to ensure exemption from local disturbing causes ; but the researches of Drs. Marcet, Daubeny, of Lenz, and of the French engineers, would appear to prove that notable differences may be found in sea water. Thus, Daubeny states, that the quantity of bromine present will vary at times from 0.915 grain in 1 gallon to 1.7 grains ; Dr. Marcet says that the Southern Ocean contains more saline matter than the Northern, in the ratio of 1.02919 to 1.02757 ; and Daubeny states, in conformity with Lenz, that the

Atlantic is salter than the South Sea, and that the Indian Ocean is salter on the west than it is on the east. It would also appear that there exists a maximum of saltness towards the north, and towards the south, of the equator in all the oceans. Engineering operations are, however, seldom carried on in mid ocean, and it is to be observed, that the differences in the composition of the waters near the shores depend more upon local or accidental circumstances than they do upon any general law. Thus, the intermixture of fresh and salt water produced by the discharge of a river into a bay, the local rate of evaporation, and even the character of the impurities the fresh waters are likely to bring down with them, will materially affect the destructive action of the sea upon building materials.

105. It is usually considered that sea water retards the setting of limes and cements, by reason of the chloride of sodium and the other saline matters it contains; and if this be correct, the following table will be of interest; it contains the saline contents in 1000 parts of sea water (as given by Mallet, "Transactions" B. A., 1840, p. 223):—

Arctic Sea . . . .	28·30	Marcet
North Atlantic . . . .	42·60	„
Equator . . . .	39·20	„
South Atlantic . . . .	41·20	„
Mediterranean . . . .	39·40	Laurent
Sea of Marmora . . . .	42·00	Marcet
Black Sea . . . .	21·60	„
Baltic . . . .	6·60	„
Dead Sea . . . .	385·00	„
British Channel . . . .	35·50	Sweitzer
Irish Sea . . . .	33·76	Mallet

But perhaps the most destructive agent, so far as the instable combinations of lime and silica are concerned, is the magnesia present in sea water ; and this varies but little in any ports hitherto observed. There are, however, very marked differences in the quantities of carbonic acid or of the hydrosulphuric acids to be discovered in the waters near large towns especially ; and as they also are very powerful in their destructive actions upon the materials exposed to them, it becomes essential to examine carefully the nature and composition of sea waters before exposing new and untried materials to them. A great deal of useful information on these subjects is to be found in the various papers lately published by Messrs. Vicat, Minard, Chatoney, Noel, &c., in the "Annales des Mines et des Ponts et Chaussées," subsequent to 1856 ; in the "Proceedings" of the Royal Institute of British Architects, and of the Institution of Civil Engineers. Mr. Mallet's papers in the "Transactions" of the British Association for 1838 and 1840 are the most practically useful of any hitherto published as to the action of sea water on iron or on mixed metals, with respect to which, also, the publications of the Royal Society and the various technical journals may likewise be consulted. The most important results hitherto ascertained being that in the composition of mortars and cements for hydraulic works in sea water, there should be present a proportion of free lime, depending upon the carbonic acid or the sulphuretted hydrogen present in the sea ; and that the contact of dissimilar metals, the scantling of a piece of cast or wrought iron, the contact of cast iron with wrought iron or steel, or even of one cast iron with another, may materially affect the rates of decomposition of the respective ingredients when immersed either in sea water or in what are

technically known as the bad waters of mines. There is, unfortunately, still a great amount of uncertainty upon the whole of this branch of applied science, to some of whose details we shall have to refer hereafter in the description of the accidents to which hydraulic works are exposed.

## CHAPTER II.

### DRAINAGE.

106. THE functions of vegetable life cannot be carried on without the presence of a certain quantity of water, inasmuch as the fluids which circulate in their tissues are almost entirely composed of the water taken up by the roots from the ground. With the exception, however, of some aquatic plants, the majority suffer from an excess of humidity; and when water is found in an agricultural district in large quantities, it is as injurious as its absence is in other cases. Thence arises the necessity for *draining* lands surcharged with water, on the one hand; and for *irrigation*, on the other. It is equally important that air should be allowed access to the roots of plants; but the operations of ploughing, harrowing, hoeing, &c., by which this object is effected, belong to the science of agriculture rather than to engineering.

107. The causes of the excess of moisture in any particular district depend upon the rain-fall, the natural configuration of the land, and the nature of the surface and the subsoils; and, conversely, the same causes influence the dryness of other districts.

108. The distribution of rain is very unequal, not only when large divisions of the globe are considered, but also over very confined areas. This is a natural consequence of the laws affecting the production of rain; for it is caused, firstly, by the heat giving rise to



evaporation, and then by the winds carrying the vapour to a distance, until it is precipitated, either by contact with the cold earth, or by meeting with another mass of air so much colder than itself as to absorb the heat which holds the moisture in solution. In the tropical regions, the rain-fall is greatly in excess of that of the temperate zones; but from the greater uniformity of temperature, it also happens that the fall is confined within a much more limited space of time; the total quantity is greater, but the number of rainy days is less, and the law appears to prevail that the number of rainy days increases with the latitude, north and south of the Equator. But local circumstances modify these general laws to a great extent; so much so indeed, that in nearly the same parallels of latitude one district may be subject to frequent floods, whilst another may be constantly, or periodically, exposed to droughts.

109. The quantity of rain, for instance, is always less on plains than it is on elevated table-lands, especially when the latter are connected with mountain chains. On the sea shore also, it is greater than in inland districts, because necessarily more vapour rises from the sea than from the land. The existence of particular currents in the ocean will at times give rise to an excess of rain on the shores round which it flows, an instance of which may be cited in the gulf stream, which causes the great rain-fall in the southern and western counties of England and in Ireland. The prevalence of certain winds will also augment or diminish the quantity of rain, according to whether they blow over surfaces able to affect in any way the amount of evaporation. Thus, in Europe, if the wind blew always from the north-east, it would never rain; whilst if it always blew from the south-west, the rain would never cease on the sea coast. It is to these

various causes that we must attribute the local differences between the number of rainy days, which, in the instance of Ireland, are about 208 out of the total 365; in that of the greater part of England, France, and the north of Germany, they vary from about 152 to 155 rainy days in the year; and in that of Siberia, it is stated that the number falls to 60. Nor are the quantities falling less variable than is the number of the days; for we find that the total quantity registered near London is, on the average, about 24·75 inches per annum; whilst near Plymouth it is about 38 inches; at Manchester, 37·5 inches; at Seathwaite, 140·6 inches; at Glasgow, 33·5 inches; and near Edinburgh, at Glen-corse, in the Pentland Hills, 36·25 inches.

110. The natural configuration of the country affects the amount of moisture retained, by the greater or less facilities it may offer for its removal. Evidently, a district presenting sharp declivities on every side, with few depressions to hold water in pools, must not only throw off the latter with great rapidity, but also furnish few means of maintaining evaporation when the fall of rain shall have ceased. The outline and direction of the watercourses also materially influence the length of time during which the water may be retained. And, indeed, the majority of cases in which marshes occur may be attributed to the physical causes connected with the surface of the earth; either, in fact, to the existence of a zone of surrounding country at a higher level, or to the existence of a watercourse in a similar relative position.

111. The natures of the surface and of the subsoils produce effects upon the humidity of a district which are more readily under control than the causes previously alluded to. They act either by retaining the surface waters, or by giving passage to the springs fed

by lands at a greater distance ; and it is of the utmost importance to be able to distinguish between these two sources of humidity, as the surface drainage adapted to the first, under some circumstances is utterly ineffectual to remedy the second.

For drainage operations, the strictly correct geological descriptions of the various strata may be neglected, and they may be divided simply into two classes, the *porous* and the *impervious*. The former comprises all those consisting of loose materials which absorb water easily and allow of its passing freely, such as gravel, sand, loamy clays, and the comminuted upper strata of most of the limestone formations. The latter consists of stiff blue clays, or of the plastic clays found in such abundance in some districts ; of some kinds of gravel cemented by argillaceous, calcareous, or ferruginous materials ; and of such limestone, sandstone, or granitic rocks as present a close grain without any fissures. No regular order of superposition of these descriptions of strata exists in nature, and from their complication arise the greatest difficulties in drainage.

112. In such cases as those in which a pervious stratum lies upon an impervious one, the water falling from the clouds permeates the former until it meets the latter. If, then, no escape be furnished by some natural overflow, the water must accumulate in the lowest depressions, until the hydrostatic pressure of that in the higher portions forces it to the surface in any lower ones whose conditions of level may be such as to allow of its rising over the surface. It may frequently happen, that a natural overflow exists at a small distance from the surface, but not at such a depth as to prevent the existence of great moisture in the main body of the stratum, although no external indication

beyond the character of the herbage may indicate the moisture. The great objects, therefore, in all drainage are, not only to remove the surface waters, but more particularly to cut off the subterraneous waters, which either rise to the surface, or are confined beneath it.

113. The removal of surface waters is a comparatively simple operation; for it may be effected by simply dressing the land into ridges, and giving these ridges an outfall into a drain or ditch all round the field. The ditch itself would pour its waters into any natural course, and the latter may at any time be enlarged or improved, by observing the principles regulating the flow of water in open channels, laid down in page 26, and subsequently, of this Treatise. The conditions to be observed being that the channel should be able to carry off, at a suitable velocity, the maximum quantity of water likely to be thrown into it within a definite period; and that the velocity should not be such as to endanger the bottom or the sides. If the outfall drain be artificially made, it is, generally speaking, desirable that it should be impermeable.

114. Operations connected with the improvement of an outfall affect very large areas, and would seem almost to call for some action of the Legislature. In many individual cases, so to speak, it is beyond the power of one proprietor to undertake them; and the only course left open to him is, to isolate his own land by diverting any water flowing from other districts, and to remove that which falls upon his own, by means the best adapted to effect that object economically. The execution of an intercepting drain will very frequently suffice to remove all the subterranean waters, should such be found, by stopping the flow of the latter in what would otherwise be their natural direction, and thus leave merely the rain-water falling over the

particular district to be dealt with. In such countries as Holland, and the fens of Lincolnshire, Bedfordshire, &c., the intercepting drain itself becomes the outfall, and a means of communication ; for the main drains are used as canals, and the waters from the low lands are pumped into them either by windmills or by steam power, as may be most expedient.

115. In hilly countries it rarely happens that any difficulty occurs from the direction or inclination of the watercourses, and in them the question of outfall is not so complicated as in the lower and more level districts near the embouchures of rivers. The longitudinal section of the centre line of nearly all the rivers is, in fact, a concave parabolic curve, the apex of which is in the elevated grounds near its source. The velocity, under such circumstances, is very great in hilly countries, and the streams are able to keep their course in a tolerably straight line, if even they do not continually tend to rectify any bends which may naturally exist. But in proportion as the rivers approach the sea, or other large rivers, they usually flow through flat alluvial deposits, or through level plains of earlier formations. The velocity of the water diminishes, and the gradual deposition of matters brought down from the hills raises the bed of the river, whilst the direction becomes tortuous from the incapacity of the stream to overcome the obstacles to its progress. In no country in the world can more striking illustrations of these laws be found than in England ; nor, perhaps, is there any country where well-directed works for the purpose of obviating their inconveniences would be attended with more brilliant results.

116. Before, however, commencing any rectification of the bed of a river or stream, it is necessary to in-

quire carefully into all the numerous commercial interests which are likely to be affected by the alteration. A plan of the existing watercourse and its various affluents, with longitudinal and transverse sections of the beds and banks to a considerable distance on each side, is required; observations upon the flood and summer levels, and upon the seasons and duration of the changes in the volume of the stream, must be made; and, lastly, a careful notice must be taken of the nature of the materials carried down, the mode in which shoals are formed or the banks destroyed, and the nature of the river-bed in its normal state.

117. If the stream follow a very tortuous course, a new channel in a direct line evidently would shorten the distance between its extreme points, and increase the inclination of the water line. The velocity of the stream would be proportionally augmented, and if the same quantity to be discharged flow before and after the execution of the new channel, its sectional area may be made smaller; or if, on the contrary, it be made of the same area as the original channel, it would be able to discharge a greater volume. Any sudden bends may thus be avoided; but it is to be observed, that there seems to exist some law, the cause of which has hitherto escaped our analysis, owing to which rivers are not able to flow in straight lines for any great distance, in other than beds of masonry, without requiring great and frequent repairs. At any rate, every stream when left to itself, so to speak, assumes a tortuous outline; and, from the experience obtained in France and Italy, it appears, that after a deviation there is always a tendency to resume the original directions, especially during the seasons of floods. It may, therefore, be preferable that the centre line of a new channel be formed with a series of curvatures of

very large radius, rather than in a perfect straight line. Upon the Rhine it was found that the river exercised no corrosive action upon its banks when the radius of curvature was about 2750 yards long, the bed of the river consisting of sand and gravel, and being frequently exposed to sudden and violent floods.

118. The efficient action of new channels can only be attained by observing these conditions:—Firstly.—They must be deepened as much as possible; the sectional area to be given will of course be regulated by the volume to be discharged under all the varying conditions of the rain-fall. Secondly.—They must not present any sudden projections, or form any sharp curves with the main stream. Thirdly.—If the new channel cannot be dug out at once to the required depth, it must not be opened to receive the waters until the *down* stream end of the old channel be closed, so as effectually to force all the running water into the new channel. Fourthly.—All obstacles, such as trunks of trees, large blocks of stone, &c., must be removed, so as to leave the watercourse perfectly clear.

119. When an entirely new outfall is to be formed, the dimensions to be given to it must depend upon the proportion of the rain-fall it may be required to carry off. This will vary, not only according to the configuration of the country, but also according to the greater or less degree of permeability of the materials used in its construction, and of the surface of the country itself. In precipitous mountain districts the rain flows off with comparative rapidity, merely from the inclination of the ground. Should, however, our observations be directed to particular mountain districts, it will be found that the discharge from granitic rocks differs very materially from that from the lias, the oolites, or

the clay formations. From the granites, the rain runs off nearly as fast as it falls, for the materials are non-absorbent, and the subordinate outlines do not present any depressions likely to retain the water. The lias is also, comparatively speaking, impermeable, as are also the clays; whilst the oolites, limestones, and gravels absorb water during the period of its falling, to give it out again when perhaps the supply may have ceased. In fact, the character of the discharge from the granites, the lias, and the clays, may be regarded as being of a torrential description, whilst that from the limestones is far more equable. In the former districts, it appears that about two-thirds of the rain flows off almost immediately in the natural watercourses, whilst in the latter, and in the gravel, the maximum quantity so flowing would only be one-third. Again, the proportion of the rain-fall which may require to be carried off will differ, according to the greater or less continuance of the rainy season. Thus, in winter it happens that the ground frequently becomes saturated with water at an early period, and it is advisable in such a case that any flood should be carried off as rapidly as it rises. The maximum quantity of rain which may fall within a given time becomes then a condition regulating the dimension of the outfall, of nearly as much importance as the average fall of the whole year.

120. An outfall having been secured, either by adopting or improving the natural facilities of the country, or by forming a new watercourse, if the source of the water deteriorating the quality of any land be not such as to be removed by surface drainage, an investigation of the surrounding district must be made, to ascertain the superposition of the strata, their nature, thickness, and respective inclinations; or, should any local circumstances prevent this



examination from being carried out on a sufficiently extended scale, small ditches or trial shafts should be sunk at the upper and lower sides of the district to be drained. The points of outburst of any springs must be noticed, and, if possible, their sources of supply be discovered. When these points are settled, the direction to be given to the drains must be considered; and, if possible, it would be advisable to make them follow the line of the longest fall of the ground. The depth, and the distance apart of the drains, must depend to a certain extent upon the description of crops to be raised, but more particularly upon the nature of the subsoil. For, in the first place, it is necessary to place the drains at such a depth as to obviate any danger of their materials being deranged by agricultural operations. In ordinary modes of cultivation, the minimum depth to which the ground is worked may be taken at 8 inches; in many others, the ground is moved to a depth of 18 inches; and for these reasons it is usual to place the drains, even in what is called shallow drainage, at such a depth that there shall be a distance of about 20 inches between their highest points and the surface of the ground. In the second place, if an impermeable subsoil be met with within a distance of 5 or 6 feet from the surface, such as to intercept the passage of the water in either direction, the drains ought, generally speaking, to be carried down to it; or otherwise the portions between each of them would only be imperfectly dried. The nature of the materials employed will also modify the depth of the drains; for if they be bulky, as in the case of broken stone, they must require a greater width than when tiles or tubes are used.

121. The width of the trenches will be regulated by

the depth of the drains, because the workmen require a greater space to work the deep than they do the shallow ones. At the surface the width is required to be greater than at the bottom; and in practice it is found that, for a depth of about 3 feet, it is sufficient to give a width of about 1 foot at the surface and of 6 inches at the bottom; for a depth of about 4 feet, those dimensions become respectively 1 foot 4 inches and 8 inches; whilst, for a depth of 8 feet, they become respectively 2 feet 6 inches and 1 foot 2 inches. The direction of the drains should be made as straight as possible, in order to avoid any interference with the discharge of the water; and they must be commenced by opening the lower portions of the district first. It is indispensable that a regular inclination be given, and that it should be sufficient to insure the flow of the water. A fall of about 1 in 200 will be found sufficient for ordinary cases, especially if the drain tiles be well laid.

122. There are several modes of filling in drains, employed by agricultural engineers, the principal of which are represented in the subjoined sketches.

Fig. 11.



Fig. 12.

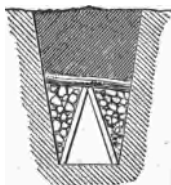


Fig. 13.

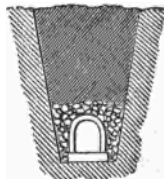



Fig. 11 represents a simple and economical system followed in countries where tubes or stones are expensive. It consists in forming shoulders upon the sides of the trenches, and laying upon them a thick sod with the grass downwards, the remainder of the

trench being filled in with the materials thrown out from it, taking care to reject the denser and more impermeable earths. This description of drain is economically formed, but it does not last for any length of time, at least with sufficient efficacy. Fig. 12 represents an economical form of drain for countries in which large quantities of water are to be removed, and where stone is cheap. The channel is formed by placing thin slabs leaning against one another on edge, and covering them with broken stones or gravel; the whole is then covered by sods and the lighter earths of the excavations, as before. If the waters draining through such channels do not contain any notable proportion of soluble salts, which they might gradually deposit around the broken stones, they will continue to flow for an indefinite period. Fig. 13 represents the tile-and-shoe drains, which were much employed in England formerly, each tile being about 14 inches long by 3 or 4 inches wide, and 4 or 5 inches high, and the shoes being of the same length, but a little wider than the tiles. Of late years, however, it has been the opinion of agriculturists, that perfectly cylindrical tubes are the most advantageous, not only on account of the greater facility of their manufacture, but also of the greater economy in their fixing. These cylindrical tubes are made of the same length as the earlier descriptions of tiles, and of diameters varying from 1 to 3 or 4 inches.

123. When the soil is peaty, or of a running sand, or when the nature of the materials through which the excavation is carried is such as to render it difficult to form and maintain the bottom of the trench in a perfectly straight line, the abutting joints of the tubes will require to be protected by collars, which may be perforated with numerous small holes. Under ordi-

nary circumstances, it will suffice either to use pipes with an end terminating thus , or those having merely a straight end. In the last two cases, the trench should only be thrown out to the precise width necessary to receive the pipes; and in both it is absolutely necessary that the straightness and the uniformity of inclination of the bottom of the trench be rigorously observed.

124. Drains should not be made too long, because, if the fall be great there would be danger from the bursting of the pipes by the head of water; and the chances of choking are considerably increased, as well as the difficulty and expense of repairs. It is advisable to make the subdrains pour their water into a species of main drain of larger diameter, which subsequently should pour the collected stream into the general outfall. Mr. Parkes recommends that the submains should never much exceed 300 yards in length, and he usually makes the diameter of the lower half about  $\frac{1}{8}$  greater than that of the upper, in order to insure the perfect discharge of the water. Under ordinary circumstances, however, it is preferable that the smaller drains should discharge into an open ditch, because the water would thence flow away more easily, and at the same time the repairs are performed with greater facility.

125. The length of the main drains may be greater, on account of their greater dimensions, but the condition above stated, of giving them an enlarged diameter at their lower extremity, must be observed. They are formed in the same manner as the subdrains, but, of course, in the lowest parts of the land; and it is advisable to place them at a slight distance below the subdrains, in order that these may discharge

more freely. Their inclination must be greater, because the volume of water they have to transmit is also greater than that of the subdrains; and it is important to carry them at some distance from the hedges, or large trees, lest the roots of the latter should force their way into the pipes and choke them; because roots are known to have a remarkable avidity for water, and are likely to force their way into the joints of the pipes. Lastly, it is important that the junction of the subdrains with the mains should not take place at right angles, but in an oblique direction, so as to avoid any interference with the velocities of the respective currents which might be likely to cause the deposition of any sand or mud in suspension in either of them. For the same reason, it is advisable, that two drains coming from different parts of the land should not be made to converge at the same point.

126. The distance apart of the drains will depend, in fact, upon their depth, and the degree of permeability of the soil; and this becomes one of the most important questions to be decided before commencing such works, for the greater the distance, evidently, the less will be the number, and the cost of the operation. Mr. Smith, of Deanstone, advocated the system of numerous drains at comparatively shallow depths; whilst Mr. Parkes and the majority of agricultural engineers now recommend that they be made deeper and at greater distances. The former made his drains from 6 to 8 yards apart, and about 3 feet deep; whilst the latter make the distance from 13 to 20 yards, and the depth from 4 feet 6 inches to 8 feet. In fact, both parties may be in error in striving to enforce their respective systems too rigorously, and a course of proceeding which may be eminently successful in one case may be very inadvisable in another. Thus, if a

stratum of permeable materials exist, whose depth may be 6 feet, it is possible that a drain placed 5 feet below the surface may withdraw the waters from a distance of about 10 or 15 yards on either side. In such a case, there would be a decided advantage in placing the drains at the greatest depths and distances, according to Mr. Parke's plan. But if the soil itself be light, and at a depth of from 2 to 3 feet from the surface an impervious subsoil be found, it would be evidently absurd to carry the drains below the subsoil, because this would entirely destroy any lateral action of the drains beyond a distance of about 6 or 8 yards. In such cases, the system recommended by Mr. Smith is the more advisable; and, indeed, it happens in this particular branch of engineering, as in all others, that every individual case requires to be judged of by, and decided upon, its own merits.

127. In Ireland the usual system latterly adopted appears to be so admirably suited to the class of materials most commonly met with, that an account of it is here given. Minor drains are formed at distances apart varying from 21 to 40 feet; the depth is made 3 feet from the lowest point of the surface; the width, from 15 to 18 inches at the top, and 4 inches at the bottom. These minor drains are parallel to one another, and only run from 150 to 200 yards without falling into either a ditch or a submain. In these drains a depth of 12 inches of broken stones,  $2\frac{1}{2}$  inches in diameter, is placed, care being taken that they be quite clean; a sod 3 inches thick is placed over them, and the earth is filled in. Sometimes pipes  $2\frac{1}{2}$  inches in diameter are inserted. The submains are cut 42 inches deep, by 20 inches wide at the top and 12 inches wide at the bottom; they are carried along the low side of the field, about 10 feet from the fences, and

are not allowed to run more than 300 yards without discharging into a covered or main drain. An open channel, 6 inches square, is formed, and above this the trench is covered and filled in, as before, with a thickness of about 8 inches of broken stones, carefully cleaned. The open main drains are sunk to a depth of at least 5 feet; they are made 2 feet wide at the bottom, and the sides are thrown out to an inclination of 1 to 1, if the materials be such as to stand at that inclination, excepting in rocky countries, where the sides may be left at about  $\frac{1}{2}$  to 1. A minimum inclination of at least 4 feet per mile is required for these main drains. The dimensions of the covered main drains must necessarily depend upon the quantity of water they are intended to carry off; but, generally speaking, it is found to be sufficient to make them 1 foot square in the clear, with walls 6 inches thick, covered by flag-stones 3 inches thick, and filled in as before.

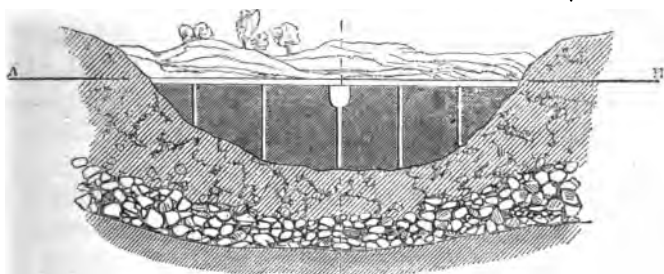
128. It appears that there is an advantage in executing the drainage of an agricultural district in dry weather, and in leaving the trenches open for a short time, in order that the ground may become warmer, and to a certain extent aerated, by being exposed to the atmosphere.

129. The measures to be adopted for the drainage of marsh lands must necessarily depend upon the causes which have superinduced this state. These causes are the following, at least in the majority of cases:—1stly, the superabundant humidity of the land may be owing to the fact that the subterranean waters are retained by beds of impermeable materials, and, after saturating the lower strata, they are forced to make to themselves a vent upon the surface; 2ndly, it may be owing to the fact that the land is situated below the level of the surrounding country, and therefore

receives the drainage from it; 3rdly, it may be owing to the existence of a river occupying a higher level than that of the marsh land itself.

130. The operations connected with drainage of large marshes, fens, or bogs, require so serious an outlay that they can only be undertaken by large companies, or by the State; but it frequently happens that small districts may be found in which a bed of clay occupies a position similar to that represented in the accompanying sketch, filling a depression upon the top of some permeable material, which last, in its turn, reposes upon a lower stratum of impermeable materials. In such cases the clay will prevent the water which

Fig. 14.



soaks through the upper and exposed portions of the permeable stratum from flowing away at the lower point. The water will then accumulate until it rises to the level of the surface of the clay, represented by the line A B, where it will overflow and form what are commonly called springs, which, unless provided with an outfall, will maintain the surface in a state of excessive humidity.

131. If, again, in the above sketch we suppose the basin-shaped depression shaded with interrupted lines to represent a bed of clay, resting upon gravel, and to



be filled in with ordinary soil, from the known impermeability of the clay it will retain all the water soaking through the soil to it, and in fact render the soil a complete morass, especially if the soil in question be surrounded by any eminences shedding their waters upon it.

132. In the illustration first supposed, the waters may be removed, either by bringing them to the surface at a point where a new and more effective outfall can be found, or by letting them escape to a lower level. In the first case, surface drains are to be cut of a sufficient capacity to hold the waters likely to rise, and transverse outfall drains made to receive them. Borings should then be made in the surface drains, descending to the top of the upholding stratum, and the hydrostatic pressure of the supply, in such portions as are placed at a higher level, will cause the water to flow into the surface drains until its level throughout the whole district will be found to be that of the drains. The outfall must be made as usual.

133. In the second illustration a boring, or borings, as may be required, are to be made through the impermeable stratum to the pervious one upon which it reposes; or, in fact, a series of absorbing wells are to be formed, and the various surface drains made to converge to it. In the Treatise upon Well-boring and Sinking much information will be found connected with the principles of the action of such wells and their mode of construction. In these instances they will serve to carry the waters from the various surface drains into the lower strata, which almost invariably will be found to possess some natural outlet, at a greater or less distance, in the shape of a spring.

134. When the succession of strata outcropping upon a hill side is more complicated than in the cases

above supposed, and is such as to produce an alternation of dry ground and marsh, the class of works to be executed may require to be somewhat different in detail, but in principle they will be found to be similar to those described. The object to be effected is, in all cases, to form a new outlet for the water; and whatever course be adopted, it must be based upon the ordinary principles of hydrodynamics applied to the particular configuration of the locality, which, again, can only be ascertained by a careful examination of the geology of the district. This examination may very frequently require to be extended over a considerable area, because the sources of supply of any springs may be found to exist at great distances, and until all the conditions affecting them are ascertained it is impossible to adopt any other than empirical methods of obviating their effects. Notwithstanding, then, the progress of science in our times, Mr. Elkington's rules may still be quoted as being the simplest and most effective for the execution of the drainage of marsh lands formed by the outburst of land springs. They are as follows:—

1st. To find out the main spring or cause of the mischief.

2nd. To take the level of the spring, and ascertain its subterraneous bearings.

3rd. To use the auger to tap the spring, when the depth of the drain is not sufficient for that purpose.

135. It must be evident, that if any district be situated so as to receive the waters flowing off from surrounding eminences, it will eventually be converted into a morass unless an outlet be provided. Should the district be small, this object may be effected, as before, by the formation of absorbing wells placed at the lowest points; but when its dimensions are con-

siderable, the first operation to be performed will consist in forming a ditch all round the marsh, so as to intercept the waters flowing from the upper lands, and at such an elevation, and with such a fall, as to insure the discharge of any waters which may be poured into it either from above, or from below. The banks, sides, and bottom of this ditch must be formed of impermeable materials. The ground contained within these banks must then be drained in the ordinary manner, and the drains made to converge to a point from which their waters may be withdrawn, either by means of an absorbing well, or by some mechanical contrivance, such as water-wheels, steam-engines, or windmills, setting in motion pumps, norias, or Archimedean screws.

136. If the marsh be owing to the existence of a river at a higher level, it must be treated in a similar manner to that just described, if the river itself cannot be diverted; or the river must be confined within impermeable banks, and the waters draining from the low lands poured into it by some of the above-mentioned engines. It may, however, happen that the stream traversing the marsh may be subject to great and sudden floods; and in such cases it is necessary to form a double row of banks, of which the outer ones must be placed at a distance, and superior elevation, sufficient to carry off the increased volume of water flowing through them at such periods. The first banks then serve to contain the river in its normal state, the second will serve to contain it during floods; the intermediate bank, or zone, may be devoted to the cultivation of aquatic plants, such as osiers, willows, &c.; or it may be drained by a separate system from that of the marsh entirely protected.

137. Of the machines used to raise water in any

of the supposed cases there are many varieties. Those hitherto applied may be stated to be—1, pumps; 2, Archimedean screws; 3, machines with buckets; 4, water-wheels with buckets, or what are called flash-wheels; 5, the water-pressure engines, hydraulic rams, rope pumps, &c.

138. Of these, the pump is the most effective when large bodies of water are to be raised from great depths, but it is exposed to the objection that the maintenance of the packing of the piston and of the pump-barrel must be very expensive when the water to be raised is so much charged with earthy matter as must always be the case with that flowing from drains. If, therefore, the height to be overcome do not exceed 15 feet, it is usual to adopt other machines. Thus, in Holland the Archimedean screw is mostly used, when the height varies from 7 to 12 feet, and in the majority of cases motion is communicated by wind-mills; when the height varies from 3 feet 6 inches to 7 feet, however, flash-wheels are employed. In our own fen districts the scoop has been applied by Mr. W. Fairbairn, with remarkable talent and success, in cases where the height to which the water had to be raised varied from 12 to 15 feet. In the East the *noria* (a machine consisting of an endless chain bearing a series of buckets, dipping into the water at the lowest point of its course, and pouring it out as it passes the upper point) has been used from time immemorial. The fifth class of machines enumerated above are so seldom used for drainage purposes that it is not worth while to dwell upon them at present. Indeed, local circumstances must modify so considerably the reasons for the choice of any one or other of these mechanical means of removing water, that it is dangerous to attempt to lay down any general law upon the subject.

The price of coals, the motive power of a neighbouring stream, the more or less favourable position of the locality so far as the action of the wind is concerned, the price of labour, and an infinite number of other details, may differ so greatly in any two given cases as to render very different modes of action necessary, or at least advisable, in the one, from the modes which would be advisable in the other.

139. Perhaps the most gigantic operation undertaken for the purpose of draining lands receiving the waters from other districts is the one lately executed for the drainage of the Harlaem Meer; and although it is rarely that engineers are required to operate upon so large a scale, a description of the method adopted is subjoined, because in principle it is identical with that which would be required even in smaller operations of the same description.

140. The Harlaem Meer, or lake, owed its origin to the excess of the rain-fall over the evaporation from the district around it, so that the waters, accumulating in the depression forming the lake, spread annually to such an extent as to absorb of late years about 150 acres per annum of its former banks. In the beginning of the sixteenth century the area was considered to have been about 9140 acres; in 1839, when it was decided to attempt the drainage of the lake, it had increased to nearly 45,000 acres, with a mean estimated depth of about 13 feet. The works have been executed by the Dutch government, who have been partially repaid by the proceeds of the sale of the land.

141. The first operation consisted in the formation of a channel for the purpose of isolating the waters of the lake from those of the surrounding country, and at the same time of serving as an outfall for the waters

to be raised. This channel is about 19 miles long, with a width varying between 125 and 138 feet, and with a depth of 10 feet, and gave rise to great difficulties owing to the want of materials fitted for its construction. Even now it cannot be said to be impermeable, and the filtrations through it must ever remain a cause of expense and probable danger. Three large steam-engines, of about 400-horse power each (nominal), raise the waters from the lake into the canal, and are stated to be able to discharge about  $238\frac{3}{4}$  cubic feet per second. They are single-acted engines, working expansively, upon the Cornish principle, and give motion to a series of pumps working at a single lift. Two smaller machines, of about 200-horse power each, are used occasionally to discharge the water from the intercepting channel, when, owing to any extraordinary tides or high winds, the natural flow from the latter is interrupted. These machines give motion to a series of flash-wheels, which raise the water about 3 feet 7 inches. The pumping was commenced, upon a large scale, in the month of March, 1849, and at the present day the whole of the surface of the lake has been brought into cultivation. The cost of these works was estimated to be, when complete, between 600,000*l.* and 680,000*l.*, or, at the higher estimate, about 15*l.* 5*s.* per acre.

142. In Ireland, some large bogs have been drained upon the system adopted in reclaiming the bog of Allen, by withdrawing the water from below, and in this case it was attended with considerable success. The surface was firstly divided into fields of an oblong figure, and of about 5 or 6 acres area, by open drains. Auger holes were driven at distances of about 33 feet down to the rock, and at a level of at least 1 foot above

the surface of the water in the drain. Curved pipe tiles,  $1\frac{1}{2}$  inch diameter, were inserted into the holes, so as to throw the water into the centre of the drain. These drains were made about 6 feet deep. On the Chat Moss drainage, no effort was made to withdraw the deeper-seated waters, but all the measures adopted were designed merely with reference to those flowing upon the surface. Square inclosures were formed, 100 yards long by 50 wide, by means of large open drains, 3 feet 9 inches deep at the minimum, 3 feet wide at the top, and 1 foot 8 inches at the bottom. Covered cross drains were formed, communicating with the open ones, and with a width of between 12 and 14 inches as far as the shoulder, placed about 2 feet 2 inches from the surface; below which point they were carried to a further depth of about 16 inches, with a width of 8 inches: these cross drains were placed at distances of about 6 yards from center to center. No tiles or pipes were used, the bottom of the drain filling being formed by the surface spit raised from the moss.

143. It frequently happens that large tracts of alluvial deposits are found at the mouths of rivers, which are alternately covered or left bare by the tides, and which, generally speaking, continue to increase until they attain such a height as only to be affected by the spring tides. These banks then become covered with a species of marine vegetation, and are cut up into innumerable small creeks, which, at the low-water, serve as channels for the inshore streams. Many banks of this description have been reclaimed from the tidal action, both in our own country and in Belgium and Holland, with such signal advantage, in many cases, as to cause regret that others should still remain unproductive.

144. The works usually required to reclaim these foreshores consist, firstly, of an embankment forming an inclosure to protect them from the sea, which must be able not only to resist the hydrostatic efforts of the external waters, but also the more destructive action of the waves and the currents; secondly, of the system of drainage of the inclosed lands, including under this head occasionally the arrangements for introducing waters charged with fertilising matters, an operation performed in some districts, and known locally by the name of "warping," to be noticed hereafter (§ 181).

145. The inclosure banks are made, generally speaking, from 2 to 4 feet above the high-water line of the equinoctial spring tides, with a minimum width of from 3 feet 6 inches to 7 feet at the crown. The outline of the bank in plan must depend upon many local circumstances; but, theoretically, it will be found to offer the greatest resistance to the normal action of the waves if it be convex seawards, whilst the stability of the materials, if it be executed in stone rubble, will be the greatest if the outline be concave. Whatever be the form given in plan, it must always be borne in mind that no sharp internal angles should be allowed, and that every projection must be joined into the body of the work by gentle curves of the largest possible radius.

146. The best form of the sea slope is a subject still much in discussion amongst engineers. On the shores of Holland and Belgium the practice has been for many years to make it rectilinear, and inclined at a small angle to the horizon. Although these slopes have succeeded in some positions, there are others in which the results obtained have been precisely of an opposite character, and in which it would appear that a vertical wall would have been preferable. Again,



many distinguished engineers are of opinion that the best form to be given is one similar to the outline the materials themselves would assume if left to arrange themselves by natural causes; whilst latterly Colonel Emy has advocated, with considerable ability, the theory that a concave transverse section was the most fitted to resist the action of the ground waves.

147. Long foreslopes possess the advantage of allowing the employment of any description of sand, or other similar materials; they offer the least resistance to the action of the sea, and are precisely the less exposed to injury in proportion as their inclination is greater. It has been observed that the destructive action of the sea exercises its greatest effect about the level of the lowest high tides of the neaps. But if these long slopes possess some advantages, they are accompanied by corresponding disadvantages; for they conduct the waves to much higher points than they would otherwise reach, and it is not always that either the materials at hand or the space disposable are such as to allow of their economical execution, to which consideration, after all, the decision as to works of this description must be referred.

148. Vertical inclosure walls occupy the least space, and expose the smallest surface to the action of the waves; and these again, instead of breaking upon the shore, are reflected towards the open sea. But walls of this description must encounter the maximum effort of the waves, wherever these do strike, and their recoil must act very injuriously upon the footings, unless they be of a very resisting description. The concave walls recommended by Colonel Emy have not yet been tried in a sufficient number of cases to justify any definite conclusions as to their merits; but they

are in many cases objectionable on the score of the ground they require, and the great expense, not only of the first cost, but of the repairs.

149. The reasons which should influence the choice of the form to be given to the sea slope of an embankment may be resumed as follows:—1. It will be influenced by the main direction of the winds, waves, tides, and currents, which should be made to strike the bank as nearly as possible in a direction normal to the surface of the facing. 2. By the materials to be procured in the neighbourhood. 3. By the surface of land which can be devoted to the formation of a bank. 4. And principally, by the commercial considerations affecting the original execution, the maintenance, and the value of the whole operation.

150. The inner slope of the banks will depend upon the materials of which it is composed; and at its foot a catch-water drain must be formed to collect the

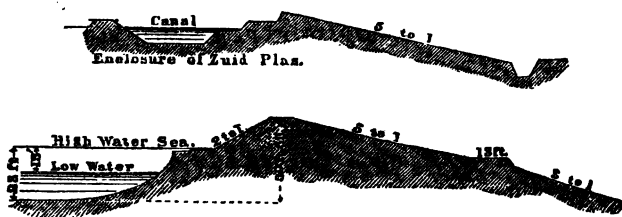


Fig.15.—Enclosure of Zuid Plas.

waters falling upon the inclosed land, and to conduct them to the outfall. The Dutch engineers usually make the slope about 5 to 1, and they form a roadway about 20 feet wide between its foot and the edge of the catch-water drain. When the bank is formed of mud or silt, it is necessary to carry up in its center a core of sand or other hard substance, to prevent rats or moles from boring through it; and means must be

taken to cover the exposed surfaces with vegetation of a character to bind together the materials of which the bank is made.

151. The land waters collected in the outfall drain are let off by means of sluices, whose apertures will be regulated by the quantity to be discharged, and the duration of the period in which the flow can take place, as well as by the head of water which may exist at the commencement of the discharge. Upon the sea coast the intervals between the tides recur with great regularity; but in the upper portions of river-courses the casual floods are likely to prevent the discharge during periods of variable duration, so that in many such positions it is very probable that the reclaimed lands may be partially, or entirely, flooded on all such occasions: the cultivation to be adopted must be regulated with a view to these contingencies.

152. The simplest mode of closing the outfall drain is by a sluice upon hinges, fixed at the outer end of a culvert, in wood, masonry, or iron, passing through the body of the bank. The floor of this aqueduct is placed at the level of the bottom of the catchwater drain, and it has an inclination outwards. So long as the head of water upon the outside of the sluice is greater than that upon the inside, it will remain closed; directly the waters upon the outside have fallen so as to form a sufficient head upon the inside to overcome the friction of the hinge, the sluice will open and give passage to the waters. It is, however, advisable that a sliding gate working in a valve be placed behind the hinged sluice, to guard against the possibility of accidental derangements of the latter.

153. Another description of gate frequently used in these works is the gate working upon a vertical axis and shutting against a rebate, in which the areas of

the two portions of the gate are made unequal. When the waters on the outside are higher than those on the inside, the gates are pressed against the rebate; when the opposite conditions occur, the gates open and afford a passage to the land waters. Sometimes, in large gates of this description, where two leaves are employed, they are made to meet at an obtuse angle, like the leaves of a lock gate.

## IRRIGATION.

154. The application of water for the purpose of assisting the growth of plants, appears to have formed an integral part of agricultural engineering even long before drainage was considered to form another part of that science. In the burning plains of Assyria, Mesopotamia, and of Asia Minor, in India and in China, and more extensively still in Egypt, works for the distribution of the great streams flowing from the mountain ridges of the great hydrographical divisions of those parts of the world have indeed existed from the earliest periods of history. It would appear, also, that the modern systems, as we proudly call them, of storeage reservoirs, both for the flood waters of rivers and for the superabundant rain-fall, were known to the engineers of the kings of Assyria, Egypt, and India; for the artificial lakes of Nitocris and Moeris, and the huge reservoirs or tanks of Bintenny, Candelay, and Mainery, which are alluded to by the earliest travellers, might still serve as lessons, or models, to our own engineers. A very interesting account of the irrigation of the nations of antiquity may be found in Jaubert de Passa's "*Recherches sur les Arrosages chez les Peuples anciens*," and the reader who may desire to pursue the investigation of this part of the subject

would do well to consult that learned work. For our present purposes, it may suffice to say that the principles and practice of irrigation so applied in the most ancient centres of civilisation were soon lost under the rule of the Macedonian and of the Roman conquerors of the ancient world. There are occasional references in the Latin books "*De Re rusticâ*," to water meadows; and the well-known passage in Virgil, "*Claudite jam rivos, sat prata biberunt*," evidently was inspired by the habitual practice of irrigation in the neighbourhood of the poet's birthplace, Mantua, which is still in the centre of the most perfectly developed system of that description of agriculture. But the works executed by the last masters of the ancient world for the application of water to agriculture were far inferior in their importance, and their scientific character, to those of the nations they had conquered; the irrigation channels and reservoirs of the latter were, indeed, in too many cases, allowed to fall to ruin, so that even before the northern barbaric tribes, or the Saracens, had finally destroyed the empire of the Cæsars, the wilderness had again invaded large districts which had been fertilised by the industry of the native princes. It is singular that we should thus be able to trace the loss of a science to one of the most highly civilised nations of antiquity, and perhaps more singular still that we should discover its revival amongst those whom it has been the fashion to call barbarians. But so it actually has been with irrigation; and the first records that we can discover of the systematic revival of its use are to be discovered in the history of the Gothic tribes of Italy, and amongst the Saracenic invaders of Syria and Spain. One of the most ancient irrigation canals of the Pyrenees bears indeed the name of Alaric; and even at the present day that system of agriculture is

only adopted, as an original national system, in the countries which were settled by the Goths or the Moors on the continent of Europe, or by the West Saxons amongst ourselves.

155. Without dwelling upon the progressive development of the science of irrigation, it may suffice for the purposes of this work to mention that in France, Spain, Italy, Belgium, Switzerland, Egypt, Syria, and India, many very important works have been executed at various periods for the purpose of distributing water over the land. In some parts of England, especially in the south-western counties, irrigation is much used, as it is in Northern Germany, parts of Sweden, and in America. The results obtained by the recent operations of the East India Company, in the Bengal and Madras provinces especially, have been so extraordinary, that the opinions formerly held, with respect to the most favourable regions for the application of irrigation, must be modified to a great extent; but it was at one time generally believed that the temperate zones were the most fitted for the application of the system. The most important works of this description have, therefore, been executed between the parallels of latitude  $25^{\circ}$  and  $57^{\circ}$  north; and the principles hereafter explained have been mainly derived from the examination of the results obtained in that district.

156. The object for which the execution of the works required to effect an irrigation is undertaken is, generally speaking, to increase the quantity of green food for the cattle required in a well-balanced system of agriculture; and it is therefore to meadows, whether natural or artificial, that irrigation, in temperate regions at least, is most commonly applied. In the cultivation of garden produce great quantities of water are often, no doubt, used; but the manner and

the conditions under which it is furnished are so essentially different from those which prevail when the water is led between banks (*in rigo, per rivum ago*), that the term "irrigation" cannot be used in speaking of this class of operation. It is, indeed, almost exclusively to the cultivation of green crops that irrigation is applied; for the rice grounds of warm climates may be considered to form an exception to the ordinary rule, and the following remarks will principally have reference to that description of operations. The term "natural meadows" will hereafter be used to express those meadows in which the vegetation is principally composed of the *Gramineæ*, such as the *Phlœum pratense*, *Lolium perenne*, *Festuca sylvatica*, *Poa pratensis*; whilst the term "artificial meadows" will be used to express those in which the *Leguminosæ* prevail, such as the *Medicago sativa*, *Trifolium pratense*, *Vicia sativa*, &c.

157. The description of soil which derives the greatest benefit from irrigation may be described, as a general rule, as being that which is the most permeable and the most easily warmed. Compact clay lands gain the least by being covered with water, because they do not easily allow that fluid to penetrate to the roots of the grasses, and they do not easily absorb or transmit the heat necessary to allow the water to produce its greatest effect; moreover, as they are very retentive, the evaporation of the water they retain near the surface positively cools the ground to a serious extent. The nature of the subsoil may, however, modify very considerably the practical application of these remarks.

158. All waters are not equally applicable to the purposes of irrigation, and great care must be exercised in their selection; that is to say, in the regions

in which irrigation performs another function than that of merely supplying the moisture necessary to enable plants to assimilate their food. This is an important observation in such cases; for, in India especially, the quality of the waters does not seem to have much influence upon the growth of the crops; but in the more temperate regions, and especially upon the artificial meadows, the chemical nature of the water becomes a matter of serious consideration. Thus, the streams which flow from forests or from peat mosses, or those which contain large quantities of the hydrous oxide of iron, are, if not positively injurious, at least but little adapted for irrigation purposes. Springs as they rise from the ground are often too cold for this use, though in Italy the *sorgenti* of the Lombard district constitute, in fact, the value of the *marcite*, or winter meadows. The waters derived from the granitic or the primary rocks, especially when the latter are characterised by the presence of large quantities of decomposable felspar, are always more advantageous than those derived from the secondary formations, on account of the potash the former usually contain. Many of the streams from the secondary formations develop the growth of the *Carex* and of the poorer description of the *Gramineæ*; whilst the waters flowing from other members of the series, such as the pure carbonates of lime, are highly favourable to the growth of the *Leguminosæ*. It is, perhaps, dangerous to lay down any invariable rule in these matters, for as the condition to be fulfilled by any irrigation water is that it should correct the natural defects of the soil it flows over, the very qualities which may be desirable in one situation might be objectionable in others. The only safe general rules, then, with respect to the choice of a



source of supply for an irrigation are, that those waters are the best which have been the longest exposed to the air, and in the proportion in which they have traversed fertile lands able to communicate some of their chemical ingredients; and it is also on account of the large quantities of fertilising matters that the waters which have flowed through large towns have thus acquired, that they become valuable as feeders to irrigated meadows. A very simple criterion, however, exists, by which the adaptation of any particular stream to the purposes under consideration may be judged, viz., the one derivable from the nature of the vegetation which naturally takes place on its banks, and on its natural bed. If these should be covered with a luxurious, vigorous herbage, and if the waters should abound in fish and mollusca, they may be considered to be fitted for the proposed use. The brackish waters of the embouchures of rivers are often highly advantageous, and cattle are known to eat the grass grown in salt-water marshes with great avidity.

159. The period of the year in which water should be poured over the land will vary, necessarily, with the latitude of the locality, and the description of crop it is proposed to raise. In very warm climates the principal function discharged by the water is to lower the temperature of the ground and to correct the drought of the climate; and evidently, in such cases, it must be applied during the summer months. In other districts, however, irrigation is expressly resorted to for the purpose of protecting the vegetation from the effects of frost, and of obviating the effects of the sudden changes of temperature which take place in the winter and in the early spring; whilst in other districts again it is an important object to retain the

alluvial matters brought down by the streams from the upper parts of their basins. To obtain the former of these objects, it is necessary to irrigate in winter; to obtain the latter, to irrigate about the equinoxes, because it is about those periods of the year that rivers are usually the most charged with alluvial matters. But there are many exceptions to these rules, dependent upon the melting of the snows on the mountain chains, or upon other conditions of physical geography; and it is also to be observed, that the very fact of the waters of a river being charged with much sediment may at times become a source of serious inconvenience; for, if a vigorous vegetation should already have grown up, the impalpable powder which would thus be deposited on the leaves of the plants would render them unfit for cattle. The time of day at which the water may be applied has also an influence upon its results, in warm weather especially. It has been observed that there is danger in applying it when the heat is the greatest; and that it is preferable to let the waters flow over the ground in the morning, or more particularly in the evening. But when irrigation is used as a preservative from frost these remarks cease to be applicable, and the water must be poured over the ground continuously.

160. If it be thus difficult to say what precise quality of water, and when it ought to be applied; it is still more difficult to say, *a priori*, what quantity is required; because the ever-varying conditions of the soil, and of the subsoil, as well as the hygrometric state of the atmosphere, must affect the solution of that problem to a serious extent. We thus find that in the Crau d'Arles the agriculturalists consider that it is necessary to pour over their lands, in dry summers, the enormous quantity of 168,000 cubic feet of water per acre, per

season of six months. In this district, the practice is to let the water flow over the land at distinct intervals, fifteen of which occur in the season; in the Haute Garonne the periods of irrigation are more numerous (they are twenty in number), but the quantity of water used is less, being 112,000 cubic feet per acre, per season. In Algeria, the French engineers calculate that a quantity equal to about 44,000 cubic feet would suffice under similar circumstances; in the eastern Pyrenees, the total quantity used per acre, in a season, is said by Jaubert de Passa not to exceed 37,000 cubic feet; whilst in our East Indian possessions the quantity usually furnished would, in the same period, amount nearly to 72,000 cubic feet per acre; or about 400 cubic feet per acre per day. Nadault de Buffon states as the result of his observations in the south of France, that the maximum quantity required during the irrigation season is about 1,200 cubic feet per day; but this calculation appears to be rather exaggerated. In our own country there would certainly be no occasion for using so large a quantity of water; and it may be of interest here to observe that in the county of Gloucestershire, the practice is to allow a stream of two inches in depth to flow over the surface, and to dress the latter with a fall of half an inch to the foot from the feeder to the drain.

161. The primary conditions for the establishment of a system of irrigation thus are, that a copious supply of water should exist at all times; and it is a matter of equal importance that the land to be irrigated should present such a configuration, as to allow the waters to flow over it with a regular current, and to insure a perfect discharge of the water after it shall have passed over the land; for directly it stagnates in the lower parts of the ground, it will develop the

growth of noxious plants. It thence follows, that in a good system of irrigation, the levels of the land must be regulated so as to ensure the following conditions : 1st, the waters must arrive by the culminating points ; 2nd, they must be distributed in equable quantities, and with an equable velocity over the lower portions falling away from those points ; and 3rd, they must be collected into the outfall drains, immediately after they shall have passed over the land to be irrigated. In fact, the removal of the waters is nearly as essential as their original introduction.

162. The water may be conducted to the higher points of the land by forming a bar, or dam, either wholly, or partially, across the line of the stream from which it is to be derived. Wherever it is possible, the adoption of the former course is preferable ; because it allows the water to be penned back, and thus to be poured over a greater surface, and from a higher point. Should this mode of raising the surface level of the water be, however, adopted, particular attention must be paid to the possible effects of the dam in flooding lands situated above it ; and it must be borne in mind, that the top water line of any intercepted stream is not a regularly inclined, though sensibly horizontal, line, but that it assumes the form of a hyperbolic curve (§ 50), which may be considered to join the natural declivity at a distance varying with the velocity of the stream. When the water is obtained from reservoirs, it is easy to regulate the precise level of the feeder, but the construction of these reservoirs requires many precautions and great practical skill. In Spain, and in India, they are often used on a very large scale, and the various reservoirs constructed in the north of England for mill purposes might, now that steam has been substituted for water power, be easily converted

for the purposes of irrigation. The discussion of the mode of forming reservoirs of this description is reserved for the division of this portion of the science of hydraulic engineering especially devoted to the subject of canals; but it may be advisable to state here, at the risk of some repetition, that the formation of the transverse dams is the most important detail of such works, and the terrible consequences of such accidents as the bursting of the Holmfirth dam, must suffice to prove the necessity for observing every possible precaution in their construction, and in preventing any infiltrations below their foundations. When these dams are constructed of earthwork, the crowns should be made of a width equal to half the clear height, and the base be at least equal to three times the same dimension. It is safer to make the principal slope on the inside; that is to say, towards the water, and to dress it into steps; and it would be preferable to make its outline in plan convex towards the water. The top should be at least two feet above the highest water line; two sluices should be placed near the bottom, one for drawing off the water, the other to allow the reservoir to be cleared; and overflows, or waste weirs, should be formed, so as to prevent the water from ever rising to the top of the dam itself. If the streams flowing into such a reservoir should be charged with very large quantities of matter in suspension during the rainy seasons, it may also be necessary to form depositing basins to receive the mud and sand they bring down.

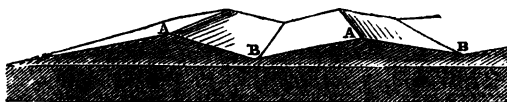
163. There are several systems for preparing the land to be irrigated, varying according to the natural configuration of the ground; but in England there are two modes of effecting this object which prevail over all the rest. These are known by the names of the

*bed-work*, and the *catch-water* irrigations. In the former, the land is thrown into beds or ridges, in directions, which are kept as nearly as possible at right angles to the main feeder, although that arrangement is by no means necessary. In *catch-water* irrigation, however, ditches are made across the declivity, at regular distances from one another, so as to catch the water flowing from the top of the field, and distribute it, again and again, over the land. The bed-work irrigation is more expensive in its first cost than the catch-water irrigation, but it is far more uniformly successful than the latter; because evidently the land over which the water flows immediately upon leaving the feeder, must receive a larger portion of the fertilizing matters it may contain than those portions receiving the water, as it were second hand. Catch-water irrigation, in fact, should only be resorted to in those positions where the declivity is too great to allow of the troughs, or distributing gutters, being made to point down the natural slope of the ground. This system is, indeed, almost exclusively practised in the hilly districts of Gloucestershire, Somersetshire, and Devonshire; although occasional illustrations of it are to be found in the northern provinces of Spain, or in the Savoy and Switzerland.

In bed-work irrigation the beds and ridges are so disposed, that a ridge may be formed having a slight longitudinal fall from the feeder, and having the ground on either side disposed with a slope towards the drains leading off the waste waters. The channels, or floating troughs, upon the ridges communicate with the main feeders, or conductors; their inclination is usually made about 1 in 500, and their length is usually limited to 70 yards; for it is considered that irrigation waters should not flow over the ground for a greater distance than the

one just mentioned, without being again restored to the parent stream. The usual dimensions of these channels is about 20 inches in width at the junction, and 12 inches in width at the end. The inclined planes on either side of the channels have a transverse inclination, varying with the nature of the soil, and the supply of water: thus in light and absorbent soils they require to be but slightly inclined, in order that the water may remain long on them, and not scour the land; whilst in compact heavy lands the rate of inclination may be increased. Generally speaking, the limits of variation, in the inclination of the sides, range between 1 in 1000 and 1 in 100, according to the nature of the ground; and the same considerations regulate the width of the planes. The more compact, indeed, is the nature of the soil, the wider may conveniently be the planes, because the water can flow upon them over greater surfaces without being absorbed; whilst in open porous soils the widths must necessarily be diminished. Upon stiff clay lands, a width of 130 feet may occasionally be given to the planes; whilst, upon porous sandy soils, 40 feet is the usual width. When the beds fall in one direction longitudinally, the crowns or ridges, A A, should be in the middle; when they fall laterally and longi-

Fig. 16.



tudinally the crowns should be made towards the upper side; and, in either case, they should project slightly above the upper edges of the planes. The dimensions and inclinations of the outfall drains, B B, at the feet of the planes must be made sufficiently

great to insure the speedy and effectual removal of the water.

164. The channels, or subsidiary feeders, receive their water from a conductor, or main feeder, which runs at right angles to them, in those cases at least wherein the supply is derived from a river which might be likely, at periods of flood, to exercise dangerous effects upon the ground, or wherein it may be considered advisable to maintain the waters under control; if, however, the stream itself should be but of insignificant volume, there can be no reason why the feeders should not be at once connected with it. The main conductor takes its origin above the weir before supposed to be placed across the stream, and should be so directed as to convey the water to all parts of the land to be irrigated; and its banks should be made a little higher than the surrounding land, so as to insure the flow of water to the latter, without its spreading laterally over the sides. Of course, the inclination and the sectional area of the conductor must be regulated mainly by the number and position of the subsidiary channels; but it is also necessary to take into account the quantity of water which may be absorbed by the earth, or lost by evaporation, during the passage of the water through the conductor. This last mentioned cause of loss may be diminished by confining the width of the canal within the narrowest possible limits. Another practical remark is also to be made, viz.: that if the river should carry down much alluvial matter, it is advisable to give the conductor a tolerably sharp fall, in order that the alluvions may not be deposited therein; an inclination of 1 or  $1\frac{1}{2}$  in 10,000 will be found sufficient for this purpose in the majority of cases. An additional reason for making the conductor as narrow as possible is to be found in this



consideration, that by so doing the smallest quantity of land is occupied.

165. The formulæ by means of which the dimensions of the main conductor may be ascertained, are those already given (§ 44); and these formulæ must be applied in countries wherein water is sufficiently valuable to make it necessary to calculate its efficient distribution. The class of workmen who usually direct such operations here are, however, rarely competent to apply those rules; nor indeed, when the usual superabundance of water in our country is taken into account, would there seem to be any occasion for the exercise of so much care and skill. In Gloucestershire it is usual to make the conducting channel for a breadth of 300 acres, about 15 feet wide by 3 feet deep; and the rule is sufficiently accurate in practice for similar districts. In warm climates, and in countries where water is scarce, the strict laws of hydraulics must be applied in calculating the dimensions of the feeders.

166. At the points where the main conductor communicates with the stream, or at those where the subsidiary channels branch off from the conductors, either permanent or temporary sluices must be placed so as to be able to regulate the admission and distribution of the water at any period. Of these implements the most important is the hatch, or sluice, at the entrance of the conductor; and it will require to be of considerable strength, in order to be able to resist the effects of any sudden freshets; for if these freshets should occur when the crop is in a forward state, and be charged with much sedimentary matter, they may produce very disastrous results. The mode of closing the subsidiary channels is a matter of far less importance; and that operation may be effected

either by the use of moveable dams, or by the use simply of pieces of turf laid across their mouths. It is often necessary to place, upon the main outfall drains, hatches of the same construction as those at the head of the feeder, in order to exclude the back currents; but evidently these hatches must be opened when the irrigation is in process.

167. All the above remarks must, however, only be considered as having a very general application; and as being always susceptible of variation, according to local circumstances. Thus, the inclination frequently given to the main conductors in the mountainous districts of the Alps, Tyrol, Savoy, Dauphiné, and Pyrenees, is  $\frac{1}{3000}$ ; whilst in the private irrigation canals lately executed in Piedmont and Lombardy, it varies between  $\frac{1}{18000}$  to  $\frac{1}{36000}$ ; and in La Provence it varies from 6 to 9 in 10,000. It would appear, indeed, that in mountainous countries the higher limits of inclination may be adopted; but that if the inclination should exceed  $\frac{1}{3300}$ , it would be necessary to retard the velocity of the stream by interposing a series of cascades, or dams, for there are very few soils which would be capable of resisting the denuding effects of the water under such circumstances. If, on the contrary, the irrigation should take place in a plain, and after the river has become tolerably clear, the inclination may, without inconvenience, be made as above stated, from  $\frac{1}{18000}$  to  $\frac{1}{36000}$ .

168. In setting out the main conductor, it is important that the radius of curvature of the changes of direction should be made as large as possible, in order to avoid any diminution in the velocity of the flow, and in the rate of discharge; and also to obviate any destructive action upon the banks. The minimum radius should be between 100 and 150 yards. The

banks should be kept at least 8 inches above the water-line, when the supply of water is constant; and it is even desirable to make that height from 16 to 18 inches, in order to guard against any inconvenience from the growth of aquatic plants, which takes place with great rapidity in such positions. The peculiar mode of growth of this class of vegetation in long festoons, it is also to be observed, produces a greater interference with the rate of discharge of the water-courses, than would arise merely from the actual volume of the plants themselves; they retard the velocity of the flow, in fact, on account of the manner in which their long streamers follow the direction of the current; and it is important that they should be cut as often as possible. The cross section to be given to the conductor must therefore be regulated by local conditions, with a view to securing the twofold advantage of economy in the first instance, and of the minimum outlay for repairs subsequently. When the channel is cut in a hard retentive rock, it must be evident that the proper section would be one approaching a rectangular figure; in any other soil, the angle of inclination of the banks must vary with the degree of its powers of resistance. A footway should be formed on both sides of the main conductor for the purpose of examining and repairing its banks.

169. In England the supply of water is usually so copious, that it is rarely necessary to measure the quantity distributed at any particular place. In warmer climates, or even here when the preliminary expense of procuring the water has been considerable, its economical value becomes, however, so much enhanced, that it is a matter of primary importance to ascertain the quantities supplied to the various recipients. The construction of gauges has, therefore,

for a long time occupied the attention of the hydraulic engineers of Northern Italy; and the researches and experiments made by them for the purpose of establishing a simple, self-acting instrument of that description, have led to the announcement of the curious law of hydrodynamics, not before observed, to which attention has been already called (§ 51), and upon which is based the principle of the gauges used in Piedmont and Lombardy. A description of these gauges is subjoined, as they may frequently be required in our colonies, or in India.

170. The unity adopted in the measurement of water in Italy is called *l'oncia d'acqua*, and it is the quantity which could flow through a rectangular orifice, discharging freely at the lower end, but not entirely into the air, under a constant pressure of four inches above the orifice. When it is desired to distribute more than a single ounce, the width only is modified, whilst all the other conditions are retained. The

Fig. 17.



Fig. 19.

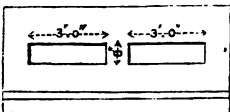


Fig. 18.

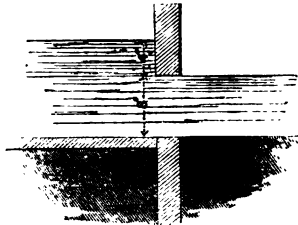
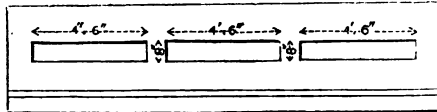


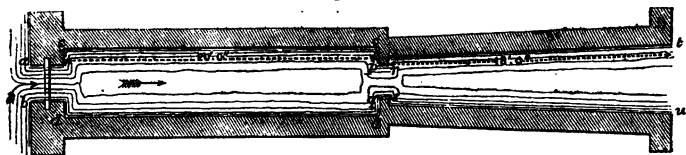
Fig. 20.



orifices of discharge are formed of the hardest description of stones to be found in the country, or occasionally of cast, or wrought iron, and are cut square

without any bevel, or the addition of anything like a funnel capable of facilitating the discharge. There are no prescriptions as to the thickness, which under these circumstances is regulated by the width of the opening; and this latter dimension is usually made of the width necessary to pass six ounces; when more than six ounces are required to be passed, the number of orifices is increased. - The conductor is formed upon the banks of the canal leading from the main stream, by means of wing walls of masonry, and the sill is usually placed at the floor line. If the ground be of a soft or yielding nature, the portion exposed to the wash of the water must be paved, especially in the part where a species of cataract will exist. The opening of the conductor *a b* of fig. 21, is made equal

Fig. 21.



in width to that of the orifice of discharge, but the height is not limited. The rectangular space *c c, d d*, is made about 20 feet in length, and 10 inches wider on each side than the orifice of discharge, and the floor of this space is laid with a rise of 16 inches in the total length, towards the orifice *g h*. At the level *c d*, of

Fig. 22.

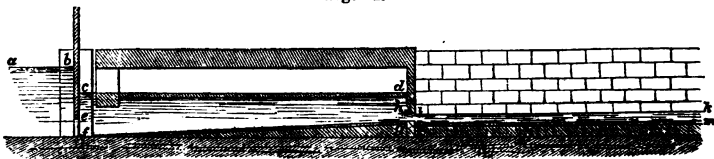


fig. 22, is a flooring, placed for the double purpose of

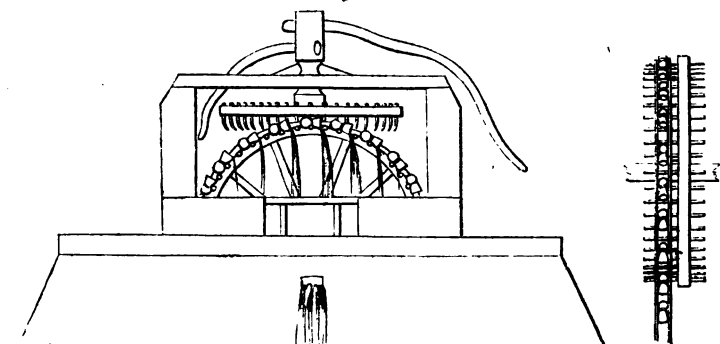
preventing the water from rising beyond the prescribed height, and for preventing any movement or agitation on its surface. The entry to this covered portion of the gauge is formed by a stone lintel, the underside of which is exactly level with the top of the orifice, and consequently 4 inches below the surface of the water; and as the height of the orifice is always 8 inches, and the rise of the inclined plane is 16 inches, the underside of this lintel is necessarily 2 feet above the sill of the sluice. Immediately beyond the orifice is the tail chamber, which is made 4 inches on each side wider than the orifice; its length is usually 18 feet, and at the further extremity its width is made 6 inches on each side wider than at the commencement. A small drip of 2 inches is formed at the commencement of the tail bay, and an inclination of 2 inches is given from thence towards the extremity. Gauges of this description require a minimum difference of level of 8 inches between the water on the respective sides of the sluice; and so cannot be applied upon canals with less than 3 feet of water.

171. It must be evident that a gauge, such as is above described, is far from being theoretically perfect. Indeed there can be no question but that the interference of the contraction of the fluid vein upon the discharge of a small orifice, must be far greater than that which takes place in a large one; and it has actually been found that the discharge through a single orifice of six ounces exceeds that which would take place through six smaller orifices of one ounce each, in the ratio of 282 to 222. For all practical purposes, however, the Italian engineers consider these gauges to be sufficiently correct; but they do not allow more than six ounces to pass through any one opening.

172. It is necessary to construct waste weirs and overflows upon the sides of the main conductor, especially when the stream from which the water is supplied is liable to sudden and considerable variations in its volume. The mode of constructing these works, as well as that of constructing the bridges, aqueducts, syphons, or other details, so closely resembles the mode adopted in canals, that their description is reserved to that portion of the work.

173. In some parts of France, and in the Milanese territory, a supply of water for irrigation has been obtained from Artesian wells; and when the spring which feeds those wells rises from a considerable depth, it is, generally speaking, of a very superior quality for the purpose in view. The higher temperature of the waters thus obtained to that of river waters, is of itself an important recommendation in their favour, and it is indeed one reason why they are principally used in Northern Italy for the "marcite," or winter meadows. At times also, the mineral elements contained in well waters are of great value; but it is

Fig. 23.



rarely that the volume they furnish is sufficient for an

extensive application. In other countries, especially in warm latitudes, mechanical means are resorted to for the purpose of raising the water to the height required; and windmills, norias (fig. 23), swapes, or *fadoufs* (fig. 24), Persian, or bucket wheels (figs. 25 and

Fig. 24.

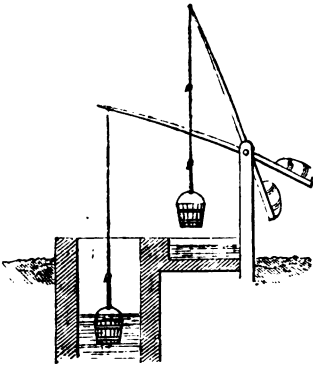
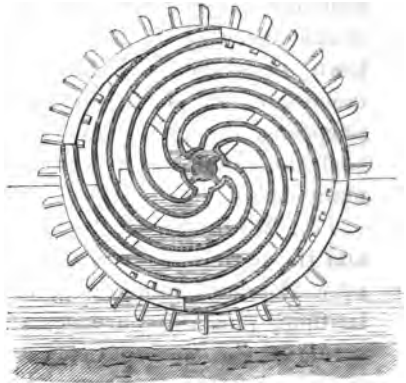
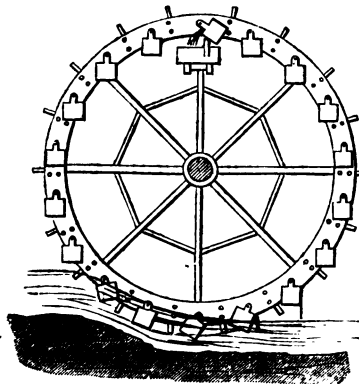
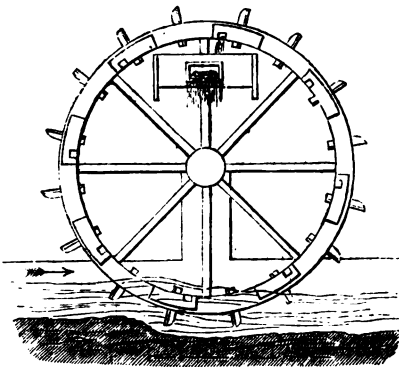


Fig. 25.



26), may frequently be seen in motion with that object.

Fig. 26.



The noria is indeed one of the characteristic instru-



ments of the Moorish agriculture, and may be observed in all the countries where the Saracens settled for any length of time ; whilst the " fadouf " may be observed in the records of Egyptian civilisation recorded in their temples, or hieroglyphical writings. In our own country steam power has been applied for raising drainage waters ; but, with the exception of the small works executed at Rugby for the distribution of the town sewerage, the author is not aware of the erection of any steam-engine exclusively for irrigation purposes, though there can be no doubt but that such an application would be highly profitable in many cases.

174. With respect to the application of the water, and the period of the year in which it should be poured over the land, much will, of course, depend on the latitude, and the purposes to which the irrigation is applied. In the south-west of England, the usual practice is to irrigate through the months of October, November, December, and January, from fifteen to twenty days at a time, without intermission ; at the expiration of that period the water is shut off, and the ground left to dry during five or six days. If a slight frost should occur, the water is again immediately turned on ; but, if there be any probability of a long continued frost, the ground is left dry. In February, the length of the periods of irrigation is diminished to about eight days, and care is taken to shut off the water early in the morning, so as to allow the ground to dry during the day time, and thus to obviate any danger from the light frosts at night. In March, the same precautions are observed ; but the periods of irrigation are gradually diminished, in such proportions that the ground shall be thoroughly dry before the end of the month. The meadows are then depas-

tured during the month of April, by sheep and lambs ; and subsequently eaten barely down before May by heavy stock. After the beginning of May, the grass is allowed to stand for hay, and in some districts it is usual to irrigate for a week before the grass is so left ; but it appears to be an invariable rule with our farmers, not to apply more water after the grass has reached two inches in height.

175. Occasionally the meadows are irrigated after the crop of hay has been carried ; but some persons consider that the grass of the aftermath is, under such circumstances, very injurious to sheep. Grass lands irrigated in summer are, in fact, known to produce the rot in those animals, though it would appear that cattle are not affected in a similar manner ; just as, in the damp meadows of Holland, the cattle thrive, whilst the race of sheep is both bad in quality and liable to violent diseases of an epidemic nature. It is known also that if the purest water remain upon land for any length of time, especially in spring or summer, it would deposit a species of white scum of the consistence of melted glue, which acts very injuriously upon the qualities of the grass. All these remarks may be applied to the other countries of temperate latitudes in which irrigation is used ; but of course they are susceptible of modification, according to the nature of the soil or of the crop to be raised from it. Local experience must, therefore, always be consulted in arranging the details of every work of this description. Indeed, the very interesting Reports by the able engineers connected with the Irrigation department of the East India Company's service show that very little is known, of a trustworthy nature at least, with respect to the proper or the most advantageous applications of water. Like all other

every-day sciences, that of irrigation has been hitherto treated with very little philosophy: the marvellous results of the works lately executed in India may, perhaps, lead to a more careful investigation than has hitherto taken place of the various questions involved.

176. There is one of these questions of detail which certainly merits more attention than it has hitherto received from our agricultural engineers, namely, whether or no it be necessary to manure the lands to be irrigated? It would appear, from what has been hitherto recorded, that the answer to this question would depend mainly upon the quantity of water to be distributed, upon the relative natures of the soil and of the waters. The German irrigators, who are able to dispose of large quantities of water, as we also are in England, have a popular proverb to the effect that "he who has water has grass;" but in the north of Italy, where the supply of water is limited, the universal practice is to manure the lands highly before commencing a course of irrigation. In the granitic districts of Northern Spain there does not appear to be any reason for the application of any fertilising ingredients beyond those which are supplied by the water itself; and even in parts of the Campine, or the plains near Antwerp, meadows are known to be annually improved, simply by the application of water without the addition of any manure. The grasses in our northern latitudes act, indeed, to convert the mineral and organic matters contained in the waters for their own nourishment; but in warmer latitudes the function discharged by the waters distributed by irrigation is, to facilitate the assimilation of the elements required for the growth of the plants, rather than themselves to furnish those elements.

177. Generally speaking, the turf, or the natural grass surface of a country laid out for irrigation, will suffice for the covering of the ground over which the water is to flow; but as it may occasionally be necessary to sow grasses for the purpose of, as it were, creating a new vegetation, it may be worth while to give a translation of the mixtures of seeds which are recommended by the most practical foreign irrigators for the various descriptions of soils. Thus, for sandy soils, a mixture is recommended composed of the seeds of—

1. <i>Phleum pratense</i>	. . . . .	2 lbs.
<i>Agrostis vulgaris</i>	. . . . .	6 „
<i>Holcus lanatus</i>	. . . . .	4 „
<i>Poa trivialis</i>	. . . . .	6 „
<i>Trifolium repens</i>	. . . . .	12 „
<i>Medicago maculata</i>	. . . . .	3 „
<i>Lathyrus pratensis</i>	. . . . .	3 „
		<hr/>
Per acre	. . . . .	36 lbs.

2. For a sandy soil with a slight mixture of clay :

<i>Phleum pratense</i>	. . . . .	2 lbs.
<i>Poa trivialis</i>	. . . . .	6 „
<i>Festuca elatior</i>	. . . . .	6 „
<i>Lolium perenne</i>	. . . . .	4 „
<i>Avena pubescens</i>	. . . . .	3 „
<i>Vicia sepium</i>	. . . . .	2 „
<i>Lotus corniculatus</i>	. . . . .	2 „
<i>Trifolium pratense</i>	. . . . .	10 „
		<hr/>
Per acre	. . . . .	35 lbs.

## 3. For calcareous soils :

Bromus pratensis . . . . .	5 lbs.
Dactylis glomerata . . . . .	4 „
Avena elatior . . . . .	4 „
Lolium perenne . . . . .	2 „
Poa trivialis . . . . .	9 „
„ pratensis . . . . .	2 „
„ augustifolia . . . . .	2 „
Medicago maculata . . . . .	2 „
Trifolium pratense . . . . .	6 „
„ fragiferum . . . . .	4 „
<hr/>	
Per acre . . . . .	40 lbs.

## 4. For stiff clayey soils :

Phleum pratense . . . . .	2 lbs.
Alopecurus pratensis . . . . .	4 „
Poa trivialis . . . . .	9 „
Festuca pratensis . . . . .	4 „
„ elatior . . . . .	3 „
Peucedanum officinale . . . . .	3 „
Medicago maculata . . . . .	2 „
Trifolium pratense . . . . .	10 „
Lathyrus pratensis . . . . .	2 „
Vicia sepium . . . . .	2 „
<hr/>	
Per acre . . . . .	41 lbs.

Of course it must not be considered that the attempt to fix these proportions is anything more than a rude attempt to fix the composition of the grains to be sown ; and every farmer must exercise his own discretion as to the precise nature of the mixture he will employ. If sowing should be resorted to, it would appear that in our northern parts of Europe the most advantageous period for performing that operation is

about the month of March; and, for the purpose of protecting the young plants, it is customary to sow some of the cereal crops at the same time with the grasses. Oats seem to be the most useful in such cases, and they are cut in flower, to be used as fodder; or the buckwheat may be used, provided it be not allowed to shed its grain, for otherwise the new plants would run the risk of being smothered by it.

178. When water is used, as in the warmer regions of the East, for garden cultivation, the manner of its application must vary essentially from that resorted to in North-Western Europe for meadow lands, on account of the different function it has to perform. In the former case the water principally acts to refresh the vegetation and to facilitate the assimilation of its nourishment, and it is therefore made to infiltrate the ground, instead of flowing over it in a uniform stream, as is the case in water meadows. The intervals between the watering of the irrigated meadows, however, enables that class of operation to be carried on more economically (so far as the mere consumption of water is concerned) than when, as in garden irrigation, the feeding channels must be kept constantly full; and thence it happens that the latter operation is rarely performed when the supply of water is obtained from reservoirs. Wherever in the East a permanent supply has been obtained, the garden cultivation has been applied; and it might almost be said that in those regions irrigated orchards and gardens take the place of our meadows. The dry, clear, burning atmosphere has indeed there rendered irrigation necessary not only for the plants, but also for the comfort of man, and even the worst regular governments have striven to secure that blessing. In the plains of Syria, and in the dominions of the

Mohammedan kings of India, great works have thus been undertaken for this purpose; and, indeed, the engineers of our East India Company have lately had little else to do with the irrigation canals of their predecessors than to repair and slightly redress them, in order to restore their efficiency. There is one difference, however, between the irrigation provided in Syria and that of our Indian possessions, viz., that the former is almost exclusively devoted to garden cultivation, whilst the latter is occasionally applied to the growth of rice, and the enormous quantities of water which the East Indian engineers are able to dispose of have enabled them to combine other commercial applications of water with the one they principally had in view. But whilst dwelling upon this part of the subject, it may be as well to observe, that at all times, and in all climates, the tendency of irrigation is to develope in the plants receiving it a growth of the leaves at the expense of the fruit or grain. This is especially the case in warm climates, where all the operations of nature take place on an extended scale; but the effect of the law is to exclude cereal crops from the system of agriculture in irrigated districts, unless the cereals themselves should be of a peculiar nature, such as the rice, and perhaps also the Indian corn. Moreover, although in India the great feeders for irrigation, canals, are at times made to facilitate a species of canal navigation, and to drive mills, the economical results of such mixed systems have hitherto been more than questionable.

179. In the warmer latitudes, as has been before observed, water is largely used for the purpose of creating artificial rice-grounds, and the conditions of the growth of that plant, as well as those of the application of water to it, are sufficiently distinct from

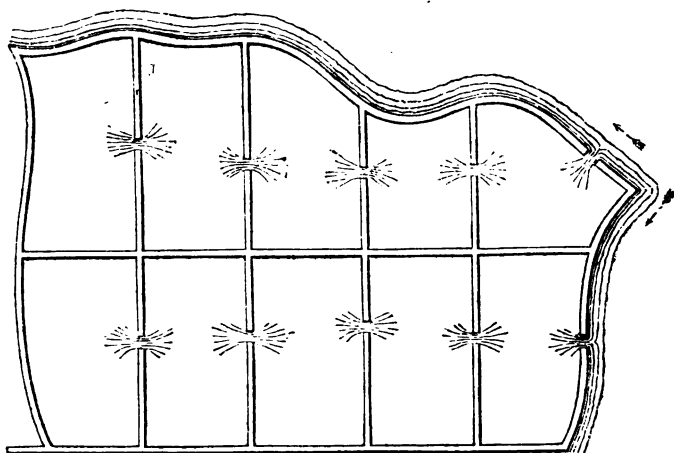
the conditions which prevail in ordinary irrigation to justify a passing reference to them. Now, the rice is essentially an aquatic plant, and it only grows in latitudes situated below the parallel of  $46^{\circ}$  north. During its growth it requires to be constantly immersed in water; and it would seem that the quality of the land upon which it is grown, is a matter of far less importance than that of the water employed; and that the water is by so much the more fitted for the irrigation of rice fields, as it is charged with the greater quantity of extraneous matter. For this reason river and pond waters are preferable to spring waters; and indeed, the coldness and purity of the latter are at times so objectionable in rice fields, that it is considered necessary to expose them in shallow reservoirs, and to mix them with animal manure before pouring them upon the land. It is usually calculated that the quantity of water required to irrigate a rice field, is about 1 cubic foot per minute, and per acre. This style of cultivation may either be permanent, or it may form part of a rotation; in the first case it is adopted because the land is marshy, either from the want of outfall, or from the springs rising in it; in the second, a species of artificial irrigation is required for every crop of rice which is to be raised from the land.

180. Whatever may be the nature of the ground to be converted into rice lands, the first condition required is, that the water should be kept continually in motion, and that all of it which is brought upon the land should be removed. A series of plane surfaces must thus be formed, so that no part of the land may be left dry, and that the water may not be allowed to stagnate in any part. After the land has been properly levelled, it is to be ploughed, and then the



retaining banks are to be formed; of these there are two sorts: 1st, the longitudinal ones, or those which have the same direction as that of the stream, and which are intended to last as long as the field is laid down in rice; and 2nd, the transverse banks, which intercept the current in an angular direction; so that when the banks are completed the rice field will be divided into a series of polygons. The sizes of these polygons is principally regulated by the difference of levels of the planes themselves; and they are made the smallest in those cases wherein the inclination is the greatest, in order to economise the labour of disposing them in horizontal planes. Moreover, the dimensions of these fields are limited by the consideration that the larger they are, the greater probability there must be that the wind may tear up the young plants. It is usual to make the banks about 6 inches

Fig. 27.



above the ground on the upper side of the field, and about 2 feet above that level on the lower side; the

width is never less than 6 inches at the crown ; but as the top of the banks often serves for a road, as well as for the immediate object of their formation, the width may vary indefinitely. They are made with the earth taken from the lower parts of the field ; and when they are roughly terminated, the water is let into the first division and allowed to rise about 5 inches all over the surface. Openings are then made in the lower banks, and water is successively let into them, so that, in fact, the whole of the field is converted into a succession of small ponds, separated by the several banks. During the whole of the growth of the plant, it is thus exposed to be irrigated by flooding ; but the extent and the manner of this flooding will vary with the health of the plant, its degree of maturity, and the violence of the wind. It becomes, therefore, necessary to regulate the admission of the water in such a manner as to be able to control its flow at any moment ; and even occasionally to shut it off entirely. After the rice crop has been carried, all the water is withdrawn, and the land is left exposed to the action of the atmosphere throughout the winter, and until the spring.

181. Before closing this chapter it may be worth while to call attention to two modifications of the system of irrigation which are often of great local value. The first of these is known in the eastern counties of England by the name of "*warping* ;" and it is, of course, under other names, largely practised abroad, whenever the natural water courses are highly charged with mineral substances in suspension. Upon the banks of the Humber, and in some parts of Holland and Northern Germany, upon the banks of such rivers as the Ganges and the Nile, it is customary to form enclosures, in which the waters of the rivers are retained, in order to deposit the alluvial matters

they contain. But there is this singular difference between the conditions under which the rivers of Northern Europe, usually employed for warping, deposit their alluvions, from those prevailing in the mighty streams named above in conjunction with them ; viz. that the alluvial matters deposited by the former are mostly brought in from the sea ; whilst those brought by the Nile and the Ganges, are almost exclusively furnished by the disintegration of the lands near their sources. Warping in the former case, can only take place near the sea ; in the latter it may, and does often, take place throughout the whole course of the rivers ; and the quality of the land so irrigated is necessarily affected by the salts or other ingredients which are obtained from the waters.

182. It is usual to surround land proposed to be thus treated by an embankment, in which are placed the inlet sluices, at the lowest level. The water enters through these sluices at the highest point of one tide, and is retained during the interval between two successive tides ; to be then run off entirely, even from the ditches, before the influx of the next. Upon the banks of the Humber it is considered that the most beneficial effects are produced by the execution of this operation between the months of June and September ; the embankments are made from 3 feet to 7 feet high, and it is usually calculated that a sluice, with a clear water way about 6 feet high and 8 feet wide, will suffice to warp a surface of from 60 to 80 acres. In this district it is found that the warped lands are at first cold and raw, and that they require a peculiar treatment for agricultural purposes. Thus, they are not favourable for the growth of corn ; oats may succeed upon them, but barley never will. The rotation usually adopted is as follows :—The new warp is sown

with grass for two years ; on the third year wheat is sown ; on the fourth, beans ; and on the fifth, wheat again. Should the ground thus warped be found to contain too much salt, it must be exposed to the air for some time before being brought into cultivation ; and at all periods it is found to be objectionable to allow the salt warp to deposit upon growing grasses. Indeed, in Yorkshire, it is customary to let the newly-warped land lie fallow for twelve months before sowing the grass, and to let on the waters after the second crop of wheat has been raised.

188. The quantity of sediment brought down by the rivers falling into the Humber is enormous. Lord Hawke stated, in his Report on the Agriculture of the West Riding, that one tide would deposit an inch of mud, and the source from whence it is derived is still a matter of great uncertainty. At its mouth the Humber is as clear as most rivers, and the floods from the upper countries, so far from increasing the quantity of matters in suspension, on the contrary, exercise a very injurious effect upon them. In the driest seasons and the longest droughts it is found to be the best and most plentiful, and produces its effect totally irrespective of the subsoil. In fact a new soil is formed, and the operation of warping differs in this respect from ordinary irrigation, which acts by improving the soil already existing.

184. The second system of irrigation referred to in § 181 is a system which acts principally by infiltration, and is applied in hilly districts as much for the purpose of obviating any ravinement, so to speak, of the vegetable soils on their inclined slopes, as it is for the purpose of irrigation strictly speaking. The feeders are in this case made as horizontal as possible, and the banks are raised, so that the water shall not flow over

the sides ; but it is allowed to permeate the soil in a manner dependent of course upon the character of the latter. In Devonshire, &c., as was before said (§ 163), a modification of this system is adopted, under the name of the *catch-water meadows*, which consists in allowing the water to flow over the edge of the lower sides of the feeders in a small shallow stream, to be collected in a series of parallel lower horizontal feeders which retard its velocity, and retain any vegetable or alluvial matters the waters might remove. A drain is usually carried from the top to the bottom of a meadow of this description, at right angles to the feeders, for the purpose of removing the water from them if required ; but the entrances to these drains are closed when the irrigation is to be effected. Catch-water irrigation, it may be added, is executed at a much cheaper rate than any other. For it is usually calculated that the first cost of laying down any large area on a system of bed-work irrigation is about 10*l.* per acre, whilst that of a system of catch-water irrigation is only about 5*l.* per acre. In the case of the Duke of Portland's celebrated water meadows at Mansfield, the total outlay was not less than 30*l.* per acre ; but as it is tolerably well known that the enhanced value of irrigated land, as compared with ordinary land, is not less than from 1*l.* 10*s.* to 2*l.* per acre, it is strange that so little attention should at the present day be paid to the subject. In India, the irrigation works have yielded at least from 40 to 60 per cent. on the outlay ; and though we cannot expect in England to obtain equally brilliant results, there is no reason to doubt but that operations of this description would still be eminently successful. The irrigation of the barren sands of the Campine, by the waste waters of the canal from the Meuse to the Scheldt, it would have been supposed would have

induced the persons interested in the suffering canal property of England to examine whether the sale of their waste waters might not compensate to them in some manner for the destruction of their carrying trade by the railways. The old Dutch engineers, who designed the irrigation of the valley of the Itchen, in Hampshire, made a very creditable attempt to apply a mixed system of canal and irrigation works, that is to say, when the state of the science of applied hydraulics in their day is taken into account; and, not to leave the county of Hampshire itself, it must appear strange that the Basingstoke canal proprietors have not attempted to apply the lesson they might have learnt from their predecessors.

END OF PART I.



THE  
RUDIMENTS  
OF  
HYDRAULIC ENGINEERING,

BY  
G. R. BURNELL, F.G.S.,  
CIVIL ENGINEER.

WITH ILLUSTRATIONS.

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PART II.

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## CHAPTER III.

### SUPPLY OF WATER TO TOWNS.

#### QUALITY OF SUPPLY.

185. THE questions which require to be considered before deciding upon the source and the means of supply of water to towns, are those connected with the qualities of the water itself, in the first instance ; and in the second, those connected with the physical conditions (as regards level and distance), of the source to be resorted to, and of the town to be supplied. All waters, it is well known, are not equally adapted for domestic use ; and those which are so adapted are rarely found in the localities where they are to be used ; so that in almost all cases it is necessary, either to bring the supply from a distance, or to raise the waters above their natural level.

186. Of late years a great deal of discussion has taken place with respect to the precise qualities required in the waters selected for town supply, and the late General Board of Health especially endeavoured to establish some rather exclusive dogmas on the subject. The discussions have borne principally upon the so-called hardness, and the softness, of the waters ; and the authorities last named pronounced themselves very decidedly in favour of the latter quality. But in this case, as in most other instances, there is far too much uncertainty with respect to the real action of the agents under consideration to warrant the assertion of any

absolute law; and the choice of a source of water supply must be greatly affected by the local conditions of economy or expediency. Unquestionably the excessive hardness of the water it furnishes may be a valid objection to a particular source, especially when that hardness is permanent in its character: but some of the chemical combinations which produce the hardness of waters, if they only act within certain limits, are stated by the most eminent pathological writers to render the waters wherein they prevail more fitted for human consumption than others wherein they are deficient. Soft waters, again, are unquestionably more pleasant and agreeable for domestic use than hard waters; but their very softness may be owing to the presence of ingredients able to affect, slowly but surely, the physical organisation of those constantly using them; whilst it is tolerably well ascertained that there is great danger to be apprehended from the action of the soft waters on some of the materials used for their distribution. At all times habit modifies the action of particular waters on the human frame; and it is notorious that people who are accustomed to any one (whether it be soft, like the waters flowing from the primary rocks; or hard, like those which have been affected by flowing from the carbonates or sulphates of lime), are always seriously affected when they begin to use another water, even though it may be of a superior quality to the one they had previously been accustomed to. Still there are waters, such as those found in countries wherein the soil is composed of the magnesian rocks, or contains the salts of magnesia or of sulphate of lime, which develope in so marked a manner the loathsome disease known by the name of Goitre, that it must be regretted that so much uncertainty should still be allowed to prevail on the whole subject of the indispensable qualities of a water supply.

187. Perhaps the most satisfactory exposition of the qualities so required is the one given in the "*Annuaire des eaux de la France*," as follows: "A water may be considered to be good, and suitable for drinking, when it is fresh, limpid, and without smell; when its flavour is hardly perceptible, and it is neither disagreeable, flat, brackish, or sweet: when it contains but little foreign matter, contains a sufficient quantity of air in dissolution, dissolves soap without leaving curds, and cooks vegetables easily." A small proportion of carbonic acid gas gives a slight flavour to a water, and renders it more agreeable to the palate, at the same time that it facilitates the action of the digestive organs by slightly exciting them. The presence of this gas in a water, even in a small quantity, must be considered useful. All authors, moreover, admit that water of good quality ought to contain air in solution; some persons have asserted that it is principally on account of the oxygen thus introduced that the aerated waters are so superior in their quality, and they even attribute the occurrence of certain endemic diseases in the mountainous districts to the absence of oxygen from the snow-waters there consumed.

188. "With a few exceptions, the waters which hold in solution a notable proportion of organic matters putrify rapidly, and acquire injurious properties. It has been proved that diarrhoea, dysenteries, and other acute or chronic diseases, have been determined endemically by the long continued use of the water of ponds, marshes, or wells containing excessive proportions of altered organic matters, either in suspension or in dissolution." The investigations of some English pathologists into the effects of certain well waters upon the health of the population using them, more than confirm the theoretical opinion thus expressed by the

French chemists from whom we have quoted; and there can no longer be any reason for the semi-hesitation with which the latter authorities assert the principle that "the smaller the proportion of organic matter contained in a water, the better it is." But with regard to effect of other fixed bodies, it is not possible to speak with similar certainty; for whilst some authors contend that air and carbonic acid are the only foreign matters which ought to be present in a drinking water, other authors contend that certain matters, in small proportions, are necessary to communicate to it a pleasant flavour, even if they be not necessary for its wholesomeness. Thus the bicarbonate of lime, when it does not exceed the proportion of 1 in 2000, is considered by M. Dupasquier, the able physician of the Hospital of Lyon, to be positively advantageous to the quality of a water for domestic purposes; but the salts of magnesia are at the present day considered to have a very injurious action upon the populations consuming the waters charged with them. The sulphate of lime, moreover, does not, in the process of assimilation, produce any of the important and desirable changes which the bicarbonate of the same base is considered to do; and the sulphate has the additional inconvenience of being easily decomposable under the influence of organic matter, when it gives rise to the production of sulphuretted hydrogen, one of the most objectionable gases to be found in water. Sulphate of lime also, it must be observed, is not thrown down by boiling, so that the hardness it produces is permanent; whereas when the bicarbonate of lime is present, the effect of boiling is to disengage the second dose of carbonic acid, and thus to reduce the lime to the state of the insoluble carbonate. This important fact with respect to the action

of the bicarbonate of lime was in some unaccountable manner occasionally forgotten by the parties connected with the late General Board of Health; and they reasoned about the loss of tea and of soap to the inhabitants of London, in consequence of the hardness of the Thames waters, utterly without reference to the change produced in them by boiling.

189. "The nitrates," again to quote the "Annuaire des Eaux," "although they appear to be present in all natural waters, occur in quantities too small, in those habitually used, to allow any rigorous conclusions to be formed as to their favourable or unfavourable action." Modern English observers are, however, far from entertaining this species of indifference with respect to the action of this particular class of impurities; and indeed as the nitrates in water are derived for the most part from the decomposition of organic matters, there is strong *prima facie* reason for objecting to their presence. The waters derived from shallow wells, especially in large towns such as London, Paris, or Manchester, are often highly charged with the nitrates; and some persons even go so far as to assert that those waters are, on that account, unfit for domestic use. In all probability there is exaggeration in the absolute condemnation of sources of supply thus affected; and it is notorious that people have consumed, uninjured, for years the well-waters it is now the fashion to decry. Nevertheless, the facts recorded by Dr. Snow, with respect to the influence of certain wells in London upon the diffusion of cholera, as well as those recorded by Drs. Letheby and Thompson, are such as to warrant us in assuming for the present, that whenever the nitrates are to be found in proportions susceptible of being numerically stated, the waters containing them are hardly fitted for domestic

consumption. It happens also that the majority of the well-waters containing the nitrates are extremely hard, and that they do not lose that character even by boiling. The presence of the nitrate of lime in the London wells may perhaps be the explanation of the existence of a peculiar fresh water alga to be found in them in great abundance.

190. It is considered by the authors of the "*Annuaire des Eaux*," that the small quantity of the chloride of sodium to be discovered in the waters habitually used for domestic service is rather advantageous than otherwise. "But it is important to remark that the chlorides, in dissolution in waters, appear to be constantly accompanied by the iodides and the bromides; and the recent investigations which show that certain plants which grow in fresh water possess the faculty of assimilating those salts, prove that the latter are almost always present. As the latter salts when administered daily, even in very small quantities, are able to produce upon the human frame an effect, which from numerous observations we are entitled to consider as of great importance, it becomes essential to ascertain in the most rigorous manner the proportions of the chlorides, iodides, and bromides in a water designed for drinking purposes. It is worthy of more than a cursory remark that people suffering under the goitre produced by the habitual use of waters containing magnesian salts, are sensibly relieved by the substitution for them of the waters containing salts of iodine."

191. The physical character of a source of water supply may influence its quality for human consumption in otherwise than in its appreciable chemical constitution. Thus, the waters which are kept in a state of motion may part with many of their noxious properties, and they may acquire the aëration of which they

would have been deficient if they were taken immediately from their original source. In the case of the water from the chalk formation, for instance, a considerable proportion of the bicarbonate of lime contained in the water rising from the natural springs is parted with by a prolonged contact with the atmosphere; and even a cursory inspection of the mills and their races, upon the banks of the river Lea, must convince any one that, if the presence of salts of lime be an objection, the maxim it was once proposed to establish, namely, that "the nearer the source the better the supply," could not be invariably true. Spring water is, indeed, popularly considered to be the most fitted for human consumption; but most scientific observers prefer river waters, provided they run over rocky or clean sandy beds, and do not receive the organised matters draining from the lands they traverse. It is dangerous to lay down any unvarying or absolute rule in these matters; and in every case it is necessary not only to observe the chemical composition of the waters it is proposed to use, but also to observe their pathological effects upon the populations resorting to them. The human constitution is a reagent far more delicate than any of those which may be used in the laboratory; and its indications ought to be studied with even more attention than the rude approximations of analytical chemistry. If, however, it be desired to establish a safe general rule, there certainly appears to be less danger in adopting the one that river waters are preferable, for town supplies especially, than those obtained from wells. In the majority of cases spring waters, like those of the valley of the Lea above quoted, are improved in quality by exposure to the air, if they, at the same time, flow with considerable velocity. They thus part with any excess of carbonic, or



sulphuric acid gases they may originally contain ; they deposit part of the earthy bases they may hold in solution ; they absorb oxygen ; and if the spring waters in their course should meet with other springs, charged with ingredients different from their own, a double decomposition may take place, and the respective waters may be purified. It does not appear, however, that mechanical agitation or exposure to the atmosphere produces any effect upon the sulphate of lime, or the chloride of calcium and magnesium, contained in spring water.

192. The deposition of the earthy salts contained in spring waters takes place in a very striking manner in the pipes and channels in which it is conveyed ; and it is on this account that it becomes especially necessary to guard against any such inconvenience in the execution of works for a town supply. In many cases this action is carried to such an extent as materially to diminish the available sectional area of the conduits, or even to render necessary the adoption of works of a very costly nature. For instance, in the aqueduct passing over the Pont du Gard the original sectional area has been contracted by the deposition of the carbonate of lime, and in many instances in our own country the same effect has been produced by that salt ; whilst in others, as in parts of Yorkshire, where the waters contain in large proportions the hydrous oxide of iron, the interior capacity of closed tubular conduits is diminished, by a deposit of that material, with remarkable rapidity. Waters of either of these descriptions would evidently be improved by a lengthened course over a clear rocky bed ; but it must always be a matter of even greater importance than the avoidance of the deposition of the salts that all possible chances of contamination from vegetable or animal matter

should be obviated, and that the atmosphere with which the waters are in contact should be pure. One of the most striking illustrations of the outlay it is at times necessary to incur in order to avoid any danger from the diminution of the sectional area of a conduit by deposition of the impurities contained in the waters, is to be found in the great aqueduct bridge of Roquefavour. This gigantic work was undertaken principally because it was feared that any reversed syphons, which might otherwise have been employed, would have been rapidly choked by the impurities thrown down from the waters of the Durance.

193. The waters obtained from wells, particularly when they are only raised in small quantities, are liable to become stagnant, and deficient in aëration; but the most dangerous effects produced upon stagnant waters are those observable in ponds, or small open reservoirs, or again in the waters of marshy or fenny districts. In all these cases the decomposition of the vegetable and animal matters, which are infallibly introduced, saturates the water with very objectionable gases, and communicates to it very repulsive and dangerous properties; nor can there be any reason to doubt the correctness of the popular opinion which attributes the occurrence of typhoid fevers, in the districts situated upon elevated plateaus of permeable rocks, to the use of pond waters; or of some forms of agues or marsh fevers to the use of the impure waters furnished by those localities. If, however, it be absolutely necessary to use stagnant waters, they may be improved by ebullition, and by a subsequent filtration through animal charcoal; whilst air should be introduced after filtration by allowing the water to fall from a height, or by a simple exposure to the atmosphere. Habich states that stagnant waters may be purified by mixing with

them a compound of 1 part of quick lime and 2 of alum, or of 4 of animal charcoal and 1 of alum, in the proportion of one of the compound to 1000 of the water in volume; this compound should be left in contact with the water for several hours, and it is said that it is preferable to leave the charcoal in contact with the water for a longer period than is required for the alum. The English engineer officers have frequently found great benefit from the use of alum alone, when it has been necessary to employ waters containing much alluvial matter in suspension; but there seems to be little reason for thus replacing the hydrate of lime, generally used for the purpose of precipitating this class of impurities, by the more costly material, alum. Latterly, Mr. T. Spencer, of London and Liverpool, it may be added, has patented a process for the filtration of water containing deleterious gases, or tinged by organic colours, through sand intermixed with oxide of iron, of which a full description will be found in the *Journal of Gas Lighting, and Water Supply*, vol. vii. No. 137, p. 22. This process was said to be especially applicable in the case of peat waters.

194. The waters of large lakes are usually of a quality intermediate between those of rivers and of ponds; but they must necessarily be exposed to acquire, in variable proportions, according to their dimensions, their exposure to the wind, and the nature of the rock on which they repose, the objectionable qualities of stagnant waters. In some cases, as in the great Swiss and Italian lakes, or in those of the mountainous regions of our own country, the waters are prevented from becoming stagnant by the passage of a great stream through them. But even in these cases it will almost always be found that the quality of the water on the line of flow will be superior to that of the water

in the body of the lake, or, in fact, that the waters of the rivers traversing them are of a superior quality to their stagnant waters.

195. These remarks upon the qualities of well, river, pond, and lake waters, have an important bearing upon the system of supply to towns, known under the name of the "gravitation system," which has been of late years largely applied in the north of England. In works of this description the rainfall from the upper districts of an elevated range of hills, is collected in reservoirs, in such a manner as to store the excess of the winter rains for distribution in the dry season, and in almost all cases the reservoirs are established on such levels as to allow of their feeding the supply pipes by natural gravitation, from whence the name of the system is derived. Evidently, in these cases, the reservoirs ought to be constructed of such dimensions as to yield the maximum quantity for distribution, precisely at the season when there would be the minimum rainfall; but this very fact creates a danger for the stagnation of the water at ordinary seasons. The purity of the water must, however, under any circumstances, depend greatly upon the nature of the ground upon which it is stored, upon the transverse sections of the reservoirs, and lastly upon their dimensions. Thus: if the ground should be of a nature to communicate any salts, to develop any vegetation, or to contaminate the water by the decomposition of any vegetable or animal matters it may contain, the quality of the supply will be fatally affected. Again, it is desirable, as far as possible, to make the transverse sections of the reservoirs such that the lowering of the water line should not leave broad belts of moistened earth or of masonry exposed; it would indeed be preferable, theoretically, to make the sides of such storeage reservoirs

vertical. But even when every possible precaution has been employed in the construction of artificial reservoirs, the waters stored in them for any length of time must become deoxygenated, and whatever chemical reactions may arise from the contact of the water with the ground, must have ample means of developing themselves. In many of our Eastern colonies the adoption of a modification of this system of storing the excess of winter rains is absolutely necessary, and the natives of those regions have, from the remotest antiquity, paid great attention to the construction of the "tanks;" just as the inhabitants of Central America have attached importance to the construction of their aguadas, or water stores; because no perennial springs, or constantly running streams, are to be found in those countries. There may be, indeed, many occasions when it may be necessary to resort to the use of artificial reservoirs; but, in England especially, it can only be on exceptional occasions that the system of storing the surplus rain, or surface waters, can be required to be applied, nor should it, in fact, be resorted to, until every other available source of supply has been exhausted. Under any circumstances, the dimensions it will be necessary to give to the reservoirs, in order to obviate any danger from the decomposition of the waters, will always be a valid objection to their construction. It must, however, be understood that practical engineering is essentially the science of the adaptation of the means employed to the end desired; and that it would be worse than absurd to attempt to lay down any invariable laws with respect to its application. Every individual case which arises should be judged, in fact, upon its own merits, and with due regard to its accidental conditions.

196. As the waters impounded in the reservoirs of

gravitation works are particularly exposed to the action of the surface soils over which they flow, it is as essential that the latter should not be of a quality to affect their purity, as it is that the ground upon which the water is stored should be insoluble. It is on this account that it becomes essential to avoid the collection of waters from "gathering grounds," as the contributing areas to such reservoirs are called, which are covered with peaty, or with agricultural, land. The former description of soils contribute not only vegetable organic impurities, but they also give rise to a very unpleasant colour; and this colour may often remain in the reservoirs, or rather appear to be inherent in their waters, when in fact those waters are perfectly colourless, and the prevailing tinge is exclusively owing to the fine peaty mud deposited at the bottom. Lands, or soils, containing oxide of iron in perceptible quantities are often as objectionable as peaty lands, on account of their influence upon the colour of the waters flowing from them, and also because the salts of iron those waters take up are objectionable in a domestic supply: but the most objectionable description of soil for the surface of gathering grounds is, without exception, an agricultural one, on account of both the organic and inorganic impurities it furnishes. Whenever, therefore, it is desired to form storage reservoirs for a town supply, the gathering grounds composed of pure silicious sand, or of the insoluble primary or secondary rocks, must alone be resorted to. Fortunately rocks of these descriptions are constantly to be met with in the hilly districts which form the best gathering grounds.

197. M. Dupasquier, from whom we have already quoted, s. 188, attaches very great importance to the temperature of drinkable water; and he asserts that, as a hygienic principle, it is desirable to drink warm

water in winter, and cold water in summer. These conditions are of course the most certainly to be met with in deep spring, or deep well waters, for they are not subject to the variations of temperature of the atmosphere; whilst river waters, and to a far greater extent, pond or reservoir waters, follow closely the changes of the mean temperature of their localities. In many cases, however, the temperature of river waters may be affected by conditions essentially different from those affecting the atmosphere, as for instance, when they are fed by snow-clad mountains; for the melting of the snow will lower the temperature of the waters, precisely when the air in the low-lands is the warmest. Under any circumstances, large surfaces of standing water must be particularly liable to be affected by exposure to atmospheric changes; and it should, therefore, be an object in their construction to place them in such expositions, and in such positions, as to reduce the action of those changes to a minimum. The susceptibility of water in large reservoirs to assume the temperature of the air must always be an objection to the introduction of a system of water supply dependent upon them.

#### QUANTITY TO BE DISTRIBUTED.

198. When the various questions connected with the quality of a water supply have been decided, it becomes necessary to ascertain—1°, the probable amount of consumption; and 2°, the certainty of being able to supply that consumption at all times. In far too many cases it may be observed that the calculations which are presented to bodies executing water-works are based upon average supplies, and average consumptions; but it is essential to remark that the rate at which the latter takes place is always the greatest at

the precise period when the former is the least. Instead, therefore, of calculating upon averages, it is advisable to reckon only upon the minimum known supply, and upon the maximum known demand, in the locality under consideration. And this observation applies with especial force to all "gravitation" schemes; because, inasmuch as they depend upon the collection of the surplus rainfall of a district, and that surplus is notoriously liable to great variations, of a nature to affect during long periods the quantity of water it is able to contribute, a reliance upon an average, of either description, will be sure to lead to serious inconvenience during periods of long continued droughts.

199. The consumption of water in a town varies greatly, on account of the differences of habits and of occupations amongst its inhabitants; and also upon what may be styled the public taste with respect to the application of water. It is more than questionable whether, under normal circumstances, the real average consumption ever exceeds 6 gallons per individual per day, that is to say, for mere personal services; and this quantity may be increased to 10 gallons per head, to allow for washing and other household purposes. But as in all towns it is necessary to provide for municipal services, and to supply water for trade purposes, it is usual to calculate upon introducing double the quantity thus indicated, or to assume that the consumption will take place at the rate of 20 gallons per head per day. So long as the old intermittent mode of supply to private houses remained in force, this mode of calculation was found to be sufficiently accurate; but of late years the system known under the name of the "constant supply" has been introduced, under the patronage of the Board of Health especially; and in almost every case wherein that system has been applied,



the consumption has increased in a most rapid and alarming manner. In London itself, where the intermittent system, however, still prevails, the consumption at the present day can hardly be considered to be less than 40 gallons per head per day; but, in some instances, where the constant supply has been given, the consumption has risen to 80, and even 100 gallons, per head per day. Of course this could not be the case if an enormous waste did not take place; but the fact is, that not only is the real consumption of water in towns increasing in a very marked and serious manner, but that it will always be extremely difficult to control the application of an article which must be supplied under the peculiar conditions under which water is usually distributed. It would be out of place here to discuss who are the proper parties to be entrusted with the execution of a water supply to a town; but it may be sufficient to state that when the supply remains in the hands of companies, it is possible, even under the constant delivery system, to keep the consumption of water within the limits of 20 gallons per head per day; whilst in nearly all cases wherein the supply has been effected by municipal bodies, the rate of consumption has attained the higher limit of 40 gallons. Indeed, at the present day, it is hardly safe in England to calculate upon a lower average rate; and as the great development lately given to the system of land drainage has materially diminished the quantity of water flowing in dry seasons in the majority of the natural water-courses, it has become almost a matter of national importance to check the profligate waste of water which seems to be gaining ground on all sides.

200. It is so essential to the satisfactory working of a town water supply that the quantity disposable should be sufficient to meet all demands upon it, that at the

risk of repeating what has been before stated (s. 197) attention is again called to the fact, that the rate of consumption is the greatest when the supply is the least. It is usually considered that in summer, the actual requirements of a town are about 20 per cent. above those of the average quantity ; whilst in winter they are as much below that amount. Messrs. Hawksley and Simpson, the engineers, who perhaps have had the greatest experience in this particular branch of engineering, gave, during the discussions upon the Liverpool Water Works, the following tables of the relative monthly draughts upon the mains of a town ; the former being the result of actual observation on the working of the Nottingham Water Company; the latter, a more general hypothetical statement.

Months.	Rate of Consumption.	Mr. Hawksley.	Mr. Simpson.
January	Consumption <i>below</i> average	4.89 per cent.	9 per cent.
February	" " "	4.82 "	9 "
March	" " "	3.63 "	7 "
April	" <i>above</i> "	0.80 "	2 "
May	" " "	1.64 "	3 "
June	" " "	5.85 "	10 "
July	" " "	5.90 "	10 "
August	" " "	3.25 "	7 "
September	" " "	3.59 "	7 "
October	" <i>below</i> "	2.33 "	4 "
November	" " "	1.71 "	3 "
December	" " "	3.77 "	7 "

201. There are two other considerations which require to be taken into account when endeavouring to ascertain the amount of consumption, especially in the case of gravitation water-works. These are, firstly, the compensation to be supplied to the possessors of water privileges in the districts likely to be affected by the interception and retention of the surplus waters of the rainy season ; and secondly, the amount of evaporation

it is necessary to provide for. Evidently the first source of consumption must be regulated by the actual state of the mill and other water property existing upon the water courses, and it can only be ascertained by a careful examination of their working power or capacity. These are questions of fact not of theory; and it would be dangerous to lay down any general or abstract laws with respect to them. It may, therefore, suffice to say that in most cases it is advantageous to the owners of water privileges that the irregularities of the streams they use should be regulated; and that they must be gainers in cases where they possess mill power by any operations which tend to give them a permanent, rather than an irregular supply. Unfortunately this is rarely considered by the juries or other tribunals, which assess the amount of compensation to be given to mill owners affected, or said to be affected, by the impounding of waste waters; and it is therefore prudent to make a liberal allowance for the supply of the compensation reservoirs it is necessary to form, in order to meet this source of consumption.

202. The allowance to be made for evaporation must depend entirely upon the physical conditions of the locality in which the reservoirs are constructed; for the rate of evaporation depending upon the rarefaction of the atmosphere, it must necessarily rise or fall with the conditions affecting that rarefaction. The average temperature, the exposition, the average rate of motion in the air, the circumstances likely to affect the hygrometric state of the atmosphere, or to charge it with vapour in suspension, must vary in every individual case; and the recorded observations upon all these modifying causes must be taken into account; bearing, however, always in mind that the supply must exceed the demand at the periods of the maximum draught.

The doctrine of averages is especially fallacious in this particular instance; for the average rate of evaporation is ascertained from the result of the observations carried on during the number of years constituting the cycle of the climate at the place under consideration. But it often happens that for three years consecutively the rate of evaporation will be greatly in excess of the average; so that it is essential to know rather the maximum rate in the locality than the probably deceptive average. In the hilly districts of the north-west of England the rainfall varies from 22 to 60 inches per annum, whilst it is estimated that the evaporation from the water surface may be considered to be safely allowed for, if the parties examined before Parliament be correct in their opinions, on the calculation of its taking effect at the rate of from 9 to 16 inches per annum. This calculation is however very questionable, and certainly in the low lands it would lead to disastrous results. Mr. Daniel records many instances in which the rate of evaporation during the hot summer months is at least double that of the rainfall; and it is even upon record that the evaporation from a large exposed water surface has amounted to as much as four inches in a day. Evidently this would be so exceptional an occurrence in England that it would not be advisable to provide for it; but the experience derived from the use of reservoirs on canals appears to indicate that, during the summer months, it is necessary to allow for an evaporation ranging between  $\frac{1}{8}$  and  $\frac{1}{4}$  of an inch per day, or for an average evaporation of from  $\frac{1}{18}$  to  $\frac{1}{12}$  of an inch per day throughout the year. In addition to this source of consumption it would be necessary to allow for the filtration into the subsoil; but the consideration of this part of the subject will be more conveniently reserved for the treatise on

canal and river navigation. It may suffice here to say that it is the greatest on light sandy lands, or on fissured limestone rocks; and that it will take place on every occasion of laying bare the bottom and sides of any reservoirs or canals.

203. Before, however, closing these remarks upon the rate of consumption of water, and its influence upon the decision as to the dimensions to be given to catchwater reservoirs, it may be advisable to state, even at the risk of repetition, that as the streams which supply them are fed almost entirely by the water running off from the land, those streams must necessarily vary considerably in volume. The range of variation will depend upon the greater or lesser equality of distribution of rain-fall; upon the configuration of the country with respect to the outlines of hill and dale; and upon the capacity of the superficial strata to absorb and retain water during wet weather, and to part with it during droughts; or, in fact, upon their capacity to store water, and thereby equalise the flow of the streams. The dimensions of the reservoirs must then depend likewise upon the distribution of the rain-fall; and it would appear that, practically, it is found to be advisable to make their capacity of storeage equal to about six months' consumption, in addition to the quantity which is likely to be lost by evaporation. A well executed system of either catchwater or thorough drainage, would unquestionably increase to a great extent the quantity of water derivable from a given area, but it will in nowise diminish the necessity for constructing the storeage reservoirs, but rather, on the contrary, augment that necessity; for as the water in such cases is directly removed, the storeage capacity of the ground itself is also diminished in the direct proportion of the perfection of the drainage. The

neglect of this simple principle has no doubt materially affected the success of some recent works, such as the Rugby and the Sandgate water-works. But for other reasons, the system on which those works were designed is an objectionable one; for the formation of a complete thorough drainage must always be an expensive operation, and when combined with the cost of the necessary reservoirs, it must lead to so great an outlay, that it may safely be asserted that the piped gathering ground should never be resorted to until every other source of supply has been exhausted. It was formerly considered that, in favourable situations, it would be possible to depend upon obtaining as much as two-thirds of the rainfall over an area so treated; but the efficiency of the drains becomes rapidly deteriorated, and certainly the marked failures of the Sandgate and of the Rugby water-works, (which were carried out on this system), have been such as to inspire great distrust of the correctness of the principles on which they were designed.

#### SOURCES OF SUPPLY.

204. After settling the various portions of the inquiry upon the important details connected with the quantity and quality of the water supply required for any particular town, it is necessary to examine the probable sources from which such a supply is to be obtained, and to ascertain their permanent conditions, under any reasonable modifications of the demand upon them. These sources may, for the purposes of the present inquiry, be classed as follows; though of course the classification itself is not presented otherwise than as a mode of simplifying the study of the subject. Local circumstances will often render it unnecessary to follow

out the details of the investigation to the extent herein sketched forth.

205. Water may be obtained from, 1° springs; 2° wells, either in the surface strata of the district, or from great depth; 3° rivers; and 4° from the surface of the ground by means of reservoirs, either with, or without, subsoil drainage.

### 1. SPRINGS.

206. The rain waters falling upon any particular district, are considered by English philosophers partly to flow off from the surface by means of the natural water courses, partly to be absorbed by the vegetation nourished by the surface, and partly to soak into the ground by the mere action of gravitation; the proportions disposed of in either manner being about the same. The water which thus soaks into the ground beyond the influence of evaporation, continues to descend, in a tolerably equable manner, if the character of the subsoil should happen to be homogeneous, so far as its capacity for holding, or parting, with water, is concerned; or in the various fissures, or veins, if the subsoil should happen to be, comparatively speaking, hard, and be, as is generally the case in such soils, strongly affected by the unequal contractions which have taken place in their mass. The descent of the water continues until it is arrested by the intervention of an impervious bed, or stratum, and it then will either flow along the top of this stratum, to some point where it meets with a natural outcrop; or it will accumulate in the water-bearing stratum itself, until it can find a natural, or an artificial relief; in the former case displaying itself in a spring, in the latter, feeding any well sunk into the water-charged portion of the subsoil. It follows from these conditions, that

the yield, as the quantity of water obtainable from a spring is called, must depend upon many very complicated circumstances, and it is therefore essential to study all the bearings of those circumstances before resorting to one of those springs for a town supply, especially if they should be exclusively fed by the surface strata.

207. The springs thus fed by the surface strata are technically known by the name of *land springs*, and in their case the rain water falling upon the loose permeable soils, descends through them simply by the action of gravity, and is never affected by any hydrostatic pressure. Land springs, in fact, never rise above the surface of the ground, but, on the contrary, their waters would rush into any depression formed in the upholding stratum, as indeed occurs with the majority of the shallow wells sunk into the superficial gravels, or drifts. It is precisely on account of the facility with which waters permeate this class of deposits, that their quality is likely to be affected by infiltrations from the surrounding soil; especially in large towns or populous districts. But in addition to this vital objection to the use of land springs, for the purposes of a town supply, an additional one exists in the fact that the water, following as it were indifferently in one or other direction, will, at any time, leave a particular well, if another well be sunk above it on the line of flow, and at a lower level; or even if it be sunk below the first one on the line of flow, and at a lower level. In fact, there is no security in the permanence of such a source of supply, and it is worthy of remark, that in no country in Europe is there any legal protection to the rights of the proprietors of underground waters. This subject will be considered hereafter.

208. *Deep-seated* springs are those which are fed by



the waters falling upon, and soaking down to great depths in any of the important members of the geological series. Sometimes the waters thus collected are intercepted in their descent by the intercalation of an impervious bed in the general mass of the rock ; and, under these circumstances, they find their way to the surface in consequence of some fault, upheaval, or other great geological disturbance, which may have intercepted the lateral passage of the water, and at the same time have furnished, as it were, a natural outlet. At other times the water-bearing stratum may pass under an impermeable stratum, and itself repose upon a second impermeable bed. Under the latter circumstances the water will flow in the greatest abundance at the level of the lower portions of the permeable stratum, according to precisely the same hydrodynamical laws it would observe if it were flowing upon the surface. If, then, an opening should be made through the overlying impermeable bed, the water will rise in the opening to a height corresponding with the hydrostatical pressure, diminished by the friction the water meets with in its traject, or perhaps also by the fact of the existence of a natural overflow. These latter overflows are indeed frequently to be found at the points where a permeable stratum passes under an impermeable one ; and their existence in such places may be explained on the supposition that the lower basin, or portion, of the water-bearing stratum being gorged, the fresh supplies, which filter through from the higher lands, can only escape at the edge of the basin. The existence of a fault may often also be observed near the natural outflows, when the latter even occur at the points where the permeable strata are covered over by impermeable ones, thus complicating the conditions of outflow ; indeed the most remarkable of the known springs are

brought to the surface by such natural causes, and it is remarkable that their volume is generally speaking greater in the cases where they occur in consequence of an interference with the subterranean flow in the body of the water-bearing stratum itself, than where they simply act as overflows at the edge of the containing stratum. The above cited classification of land and deep-seated springs must, however, not be considered to have any great philosophical value. It merely expresses the apparent physical conditions of the sources of supply, without much relation to their relative importance ; and perhaps it would be more logical to apply the term **land springs** solely to those which are fed by the superficial gravels or sands of a diluvial character, such as were for ages the sole resources of towns like London, Manchester, Paris, Southampton, Ipswich, &c.

209. **Important deep-seated springs** are to be met with in almost every geological formation of the secondary and tertiary series, with the exception of the clays and retentive marls which occur in such abundance ; but they are most common in the various limestone rocks. In the primary formations it may be stated that no deep-seated springs occur ; for their impermeable character opposes an effectual resistance to the accumulation of water below the surface, so that unless they are covered with detritus, or are traversed by numerous fissures, these formations are characterised by water courses of a very irregular and torrential description ; the springs they yield are merely land springs, often numerous and easily perceived in wet weather, but soon drying up in the summer. In the secondary and tertiary strata, however, the springs are rarer, but of far greater volume than they are in the primary series ; and, indeed, the Abbé Paramelle very justly observes that there is a species of relation between the number and

the abundance of the springs in a formation. The law he suggests is, in the main, true, viz.: that "the rarer the visible springs may be, the more copious they would be when found;" and he thence infers, that if at any time a copious visible spring be discovered, it may safely be asserted that no others are to be met with, in the same formation, within a considerable distance, especially if its surface should occupy a higher level than that of the spring. The most copious springs known are those to be met with in the secondary series, such as the Fountain of Vaucluse, the sources of the Loiret, of the Touvre near Angoulême, of the Louype near Souillac, of the Thames itself; whilst the sources of such streams as the Rhône, the Arve, or the Ganges, being entirely fed by the melting of the ice in the glaciers from which they issue, can hardly be considered to come under the designation of springs.

210. In our own country the chalk-formation exhibits some of the most striking illustrations of the conditions of flow of under-ground waters; and in many places it throws off streams of extraordinary beauty and volume. Thus, near Amwell and Chadwell, in close proximity to the outcrop of the basement beds of the London clay, and also upon a line of geological disturbance which passes under London and is connected with the outburst of the springs at the head of the Ravensbourne on the south side of the Thames, are found the celebrated springs which originally supplied the New River. At Bury St. Edmund's, Suffolk, a very powerful spring, called the Mermaid's Pits, is brought to the surface on the side of a valley transverse to the main axis of the chalk,—and which is no doubt attributable to a fault. Near Southampton, the Otterbourne spring rises close to the point of junction of the basement beds of the Hampshire tertiaries with the chalk; whilst near

Weymouth, the springs of Sutton Poyntz and of Upway are brought to the surface at points where the great fault traversing that portion of Dorsetshire affects both the chalk and the upper oolite. In the districts where the carboniferous strata are found, the effects of the numerous faults, and cross throws, which intersect the country, are even more strongly marked than they are in the more recent strata; and in the portion of the West Riding of Yorkshire, near and around Halifax, an immense number of springs are given off wherever the regular stratification of the beds is interfered with by the upheavals which have there so strangely fissured and contorted the whole surface of that district. In the old red sandstone formation the same phenomena may be observed, copious springs are to be found at the lines of disturbance so commonly to be met with in them.

211. Deep-seated springs, such as the above, are naturally more constant in their volume than land springs, in precisely the same proportion in which their supplying strata are more extensive, or of greater storeage capacity. It is, however, impossible to predicate what may be the quantity of water permanently obtainable from any one of them, unless a careful survey shall previously have been made for the purposes of ascertaining the area of the exposed permeable surface likely to affect the supply; of the relative conditions of level of the ground, and of the spring as it flows naturally; and of the levels of any natural outflows from the water-bearing stratum near the locality under examination. But even such an investigation, however carefully made, will not dispense with the necessity for a consecutive series of gaugings of the spring under all the varying meteorological conditions of the locality. And it is important here to observe

that the gaugings of a spring, or of a water course, made during two or three months only, are not likely to furnish any reliable data, especially in the case of the superficial springs; because as they are supplied by the rain-fall, it follows that they must vary more or less with the variations of the weather. Unless, then, observations be extended over several years, indeed over the whole cycle of the climate (in England this is of about seventeen years' duration) the indications to be derived from gaugings over short periods are very likely to mislead in calculations with respect either to the average or to the minimum flow. The period of the year when gaugings are taken will materially affect the correctness of the observations, if only a few isolated ones can be taken; because not only does the rain-fall vary with the seasons, but it has also been ascertained that the springs of any depth are affected at an interval of from one to five months from the period of greatest rain-fall, according to the nature of the ground. As the greatest quantity of rain falls in north-western Europe during the later autumnal and winter months, it appears, that if it be necessary to confine the practical observations upon the volume of a spring within very short periods, the most advisable course is to make them during the months of September and October; for generally speaking the springs are the lowest at that period. Even if made in those months, such isolated observations are, however, very likely to be fallacious; and, as was said before, unless they extend over the whole cycle, the yield may occasionally fall short of the quantity calculated upon in a very serious manner. Nevertheless a very imperfect series of gaugings, combined with a careful surface geological survey, will furnish indications of sufficient exactitude to prevent the absurd outlay which has sometimes been

incurred in an empirical attempt to pump dry springs of this nature. It is positively a fact that latterly, under the advice of one of the Inspectors of the General Board of Health, an attempt was made to pump dry one of the most copious of the deep-seated springs mentioned above.

212. For the purposes of a town supply, then, springs can only be resorted to when their volume is known to be constantly in excess of the maximum demand to which they are likely to be exposed ; and at all times their pathological effects must be carefully studied. Under favourable circumstances they furnish an invaluable resource, especially as their waters are almost always characterised by an equality of temperature, a condition so essential in a water intended for drinking purposes. But it is rare to discover deep-seated springs of a volume sufficient for the supply of a town, and it then becomes necessary to sink wells, or to adopt some other means of supply.

## 2. WELLS.

213. Wells may be either *shallow*, *deep*, or *Artesian*. Shallow and deep wells are those which are sunk through a permeable stratum, and form as it were reservoirs into which the land springs may filter and accumulate ; whilst the Artesian wells are those which are sunk through an impervious upper stratum, to reach a subterranean water-bearing stratum lying in its turn upon an impervious upholding bed. In the former cases, the quantity of water obtainable is simply that which can filter through the sides of the well to replace the water removed, or which may accumulate in any reservoir formed below ; whilst in the latter case the quantity obtainable will depend simply upon the power of the water-bearing stratum to transmit water.

214. In the case of shallow wells the area of the contributing strata is usually very limited, for it must be confined to the portions which are able to drain towards the well. These portions are, in fact, comprised within a reversed cone, whose apex is the bottom of the well, and whose horizontal base may vary according to the greater or lesser permeability of the stratum itself. In sands and gravels the diameter of the base becomes practically infinite, but the mere necessity of interposing an almost solid wall to prevent their running into, and filling up the well, creates a resistance to the influx of water. In the permeable, or fissured, secondary or tertiary series the lateral flow of water to a well does not take place with the same ease that it does in the lighter superficial deposits; so that the above cited law as to the form of the contributing area may be more distinctly observed in them than in gravel or sand. No general law can be said to exist as to the rate of the transmission of water, so that in all cases wherein it is advisable to resort to shallow wells, it will be advisable also to establish a series of observations upon the rate at which similar wells in the same formation are refilled, after being pumped dry. But the most important observation to be made with respect to shallow wells is that, when formed in towns, they are especially liable to be affected by the infiltration from drains, sewers, or cesspools, and thus to take up the nitrates which we have before seen (ss. 189, 193) constitute the most objectionable ingredients to be found in a water intended for human consumption. To such an extent, it may be advisable here to repeat, are shallow wells in towns exposed to be thus contaminated, that many able observers have recommended that their use should be strictly forbidden by the authorities entrusted with the care of the public health.

But it is not yet satisfactorily proved that, although unquestionably the waters of shallow wells are often hard, and may be often dangerous, the presence of the salts of nitre is so decidedly fatal, as to justify the neglect of a source of supply which, in London especially, yields a very agreeable water. There has been, in this matter, somewhat of the hasty dogmatism which characterises modern official science; but unfortunately the public is little able to discriminate the value of the opinions uttered by such authorities as those now alluded to. However this may be, it must evidently be important that the wells sunk in populous districts should be protected from any danger of contamination by the infiltration from sewers or cesspools; and the extent to which this danger may extend must depend upon the permeability of the water-bearing stratum itself.

In the case of deep-seated wells, the probable yield of water must depend primarily upon the area of permeable strata, likely to affect the supply, and upon the facilities those strata may offer for the passage of water; and secondly upon the rate of consumption, which takes place in the neighbourhood, for the quantity of water which any particular stratum can supply is only a limited quantity, so that evidently, if the water be taken at one point, no more will remain for the other. It is also essential to observe, in these matters, that there is at present no legal mode of creating a vested right to underground waters; and that, therefore, if the authorities of the town should resort to a deep seated well, there is no legal guarantee to protect them from the interception of their waters by any person who may choose to sink a well near to them. Difficulties of this description have actually arisen, and to cite one striking case it may suffice to refer to the



celebrated action recorded in Gale on Easements, between Acton and Blundell, (p. 181, ed. 1849), which as strangely illustrates the ignorance even of the most learned judges, in questions affecting natural laws, as it does the abstract justice of the principles the old Roman, or the civil, law was founded upon. But the most remarkable illustration of the effect which may be produced even in a comparatively large water-bearing stratum by pumping on a large scale, is to be found in the fact, that the water line of the chalk formation under London has been, according to the observations of engineers and geologists, permanently lowered to the extent of 50 or 60 feet below Trinity high-water mark; and it is even stated that the level of the water in the wells near the summit for this formation rises on the Monday morning, in consequence of the cessation of pumping in London during the Sundays. But with respect to the particular formation thus referred to, it must be observed that the subterranean disturbances to which it has been exposed have introduced some peculiar conditions in the flow of the water it contains, whereby the wells on the south west of London are protected from the effect of the great abstraction of water in the metropolis. There is, in fact, a line of upheaval which traverses the valley of the Thames from east to west; and one, if not more lines of upheaval running from north to south; so that the passage of the underground waters is intercepted, and the level of the water in the chalk wells of north Kent is considerably above the level observable in the wells of Middlesex. These observations can hardly be followed up to their full extent in the present treatise; but they show how wide must be the range of study of those entrusted with the execution of a town supply, and how necessary it is to trace, not only

the apparent, but the hidden causes which are likely to affect the desired results. The result of the pumping operations at Liverpool might also be referred to as illustrating the conditions affecting deep wells.

215. If, however, it should have been ascertained that no geological disturbance of the water-bearing stratum (in which it is proposed to sink the supposed well) exists, the yield of that well may approximately be calculated, as was before stated, by observing the area, and the elevation of the district situated above the water line, and the rate at which a definite quantity of water may pass through the rock. In some formations not only does the water find its way through the body of the deposit by a uniform permeation, but it collects in large sheets, or streams, in the cross fissures so often met with in stratified deposits; and when this is the case, the rate of supply may, and in all probability will, be increased; but at the same time there will be a greater risk from an accidental interception of the stream. The flow of such underground streams will naturally be affected by the hydrostatic pressure, or head, under which they exist, and very often that head may be such as even to cause the water flowing into a deep-seated well on a low level, to rise above the surface of the ground, and thus to produce the appearance of a true Artesian well. It is supposed that the principal wells and springs of the chalk are supplied by fissures of this description, and certainly the passage of water through that material does not take place with sufficient rapidity to account for the large quantities obtainable from those wells. The same law appears to hold with the oolites, the new and the old red sandstones, and it is on this account that the abstract theoretical reasoning, with respect to the flow of water in an underground well, may be so

strangely belied by the actual results obtained. After all, well sinking is but an empirical art; and nothing but a practical experiment can solve the real capabilities of any particular work of that description.

216. It is necessary to observe the precautions before recommended in order to guard against infiltrations from drains or cesspools, in the case of deep-seated wells, just as it is necessary to observe them in the case of shallow ones. Moreover, as the water in deep wells remains for a comparatively long time in contact with the masonry lining, the latter must be carefully executed of such materials as are not likely to affect the quality of the water, and as far as possible it is desirable to ensure a rapid renewal of the fluid which stands in the bottom of the well, in order to obviate any inconvenience arising from its stagnation. Surface drainage must be carefully excluded; and it certainly is advisable to cover the top of the well, in order to protect the water from light, or atmospheric impurities.

217. Artesian wells are those in which the water is obtained by means of an excavation, or a boring, carried through an impermeable surface stratum, lying upon a permeable water-bearing stratum; which in its turn lies upon an impermeable one, and outcrops at a level so much above that of the surface of the ground near the well as to cause the water in the intermediate bed to flow over the said surface. Artesian wells form, as it were, artificial outlets for the waters contained in the lower parts of the basin, and the water line in them will therefore depend upon the hydrostatic pressure existing upon the water in the lower parts; or in other words, upon the head produced by the level of the supplying ground. The conditions of success in an Artesian boring depend upon the perfection and regularity of the basin filled by the water-

bearing stratum, so far as the mere retention of the water in the latter is concerned; and upon the level of the streams flowing upon the surface of the water-bearing stratum, so far as the height of the water-line is concerned. In fact, the quantity of water to be obtained from an Artesian well must be regulated by the area of outcrops of the water-bearing stratum; and that this quantity is far from being unlimited is proved by what has occurred at London, Tours, Milan, and elsewhere, when a great number of wells have been sunk into a water-bearing stratum of small capacity. But there are several curious physical conditions connected with the subterranean disturbances to which all strata are exposed, which are able occasionally to falsify any theoretical reasoning with respect to the yield of wells of this description. Thus in the valley of the Loire, several successful works have been executed, wherein the average depth of the wells was about 500 feet; whilst in one case the boring was discontinued, after having been carried through the ordinary water-bearing stratum to a depth of 628 feet; and in a second case after having been carried to a depth of 454 feet, without meeting with a supply. The celebrated well of Grenelle yields about 800,000 gallons per day, from a depth of 1802 feet, the supply coming from the lower green-sand, which is there found to be intercalated in the regular geological order between the gault clay, and some lower impermeable stratum. But at Calais, an Artesian boring 1150 feet deep, was carried through the chalk and the upper members of the subcretaceous series, and left off in one of the members of the carboniferous deposits. At Highgate something of the same kind occurred, for after passing through the gault clay the boring was carried into a series of clays and sand-

stone, which appears to belong to the new red sandstone division of rocks; and later still, at Harwich, the boring, after passing the gault, entered at once into the earlier slate rocks. At Chichester a boring of 1054 feet in depth, was carried into the upper greensand, but no water was obtained; and at Southampton the boring was discontinued at a depth of 1317 feet from the surface (being still in the chalk) without having obtained a supply of water. In the cases above cited of Highgate, Harwich, and Calais, it would appear that the continuity of the water-bearing stratum has been interrupted by the projection of some isolated patches of an older formation, an accident which it would be impossible to foresee; and it therefore must always be observed, that the science of Geology may furnish safe data for reasoning as to what we can *not* find in any particular position, whilst it by no means can assure the inquirer as to what he will find.

218. It is quite as impossible to predicate the quantity of water to be obtained from an Artesian well, as it is to predicate the success of the attempt to find water by that means. Even under the most favourable circumstances these wells do not yield very large quantities of water; and the Grenelle well which, as was said above (s. 217), pours forth 800,000 gallons per day, when the pipes are clear, (for it is necessary to remark, that occasionally they become choked) is amongst the most successful operations of this kind upon record. But in consequence of the increase of temperature in proportion to the depth of a well, or excavation, another serious objection arises to this class of wells, viz., that if the water-bearing stratum should descend to any great depth, the water it will yield will rise at an inconvenient temperature. The physical laws affecting this matter, are as follows:—

219. The temperature of the ground is affected by the state of the atmosphere to a certain distance from the surface, where that temperature becomes constant; and beyond this point it increases according to a law susceptible of modification by local circumstances. It is said that in Scotland the rate of increase of temperature, after the permanent degree has been attained, is about  $1^{\circ}$  of Fahrenheit for every 48 feet of descent. M. Walferdin found that the rate of increase at Paris was  $1^{\circ}$  Centigrade for 30·87 of descent, or  $1^{\circ}$ ·8 Fahrenheit for every 102 feet 10½ inches; and M. de Girardin found that at Rouen it was, in one case, about 1·8 for every 67 feet 4 inches, and  $1^{\circ}$ ·8 for every 100 feet of descent in another. Some accurate experiments made at the well of Grenelle showed, that the increase of temperature there was with remarkable regularity  $1^{\circ}$ ·8 for every 106 feet of descent below the point of constant temperature, which is about 93 feet 6 inches from the surface of the ground at the Observatory of Paris, and marks a little above  $53^{\circ}$  Fahrenheit. This would give a minimum rate of increase, in the more recent secondary and tertiary districts of North Western Europe, of about  $1^{\circ}$  Fahr. to every 59 or 60 feet in descent, though of course local circumstances may especially affect the temperature of underground waters. For instance, the springs which supply the King's bath, at Bath, rise at a temperature of  $117^{\circ}$ ; and the wonderful spring of Orense, in Gallicia, rises at a temperature of not less than  $180^{\circ}$ . But even if no abnormal cause should be at work to raise the temperature of the water, the latter will necessarily be regulated by the relation above stated to exist between the distance from the surface from whence the spring rises, and the internal temperature of the globe.

### 3. RIVERS AND THEIR APPLICATION TO TOWN SUPPLIES.

220. It would thus appear that, in order to meet the requirements of a large agglomerated population, the most infallible natural source of supply is to be found in rivers, though there are, unquestionably, many serious objections to them. Thus it almost always happens that they receive the drainage waters from cultivated lands and inhabited districts ; and the daily spreading habit of making their beds serve as the outfall for town sewerage tends seriously to increase this evil. Indeed it would be impossible to cite an instance in which so much mischief has been produced by injudicious attempts to enforce prematurely what would otherwise be a great social benefit, as the one which is to be met with in the systematic pollution of the rivers and water courses by the towns which acted under the advice and control of the late General Board of Health. In England, of late years, it is positively the fact that a body of men who were specially appointed for the purpose of protecting the public interests against local selfishness or local ignorance, have tolerated, if even many of its leading officers did not actually advise, that town sewerage, rendered more than usually offensive by the universal adoption of the water-closet, should be cast into the upper portions of the courses of rivers, resorted to by dwellers lower down on their banks for the water required for domestic purposes.

221. In rivers which are likely to be affected by the tidal action, there is another source of danger from the transmission of the salts contained in the sea water ; and it is to be observed, that in consequence of the minute diffusion of those salts their presence may occasionally be detected even in the parts of a river situated above the point where the mechanical action

of the tide ceases to influence the level of the stream. Thus, in some seasons the muriate of soda has been found to exist in perceptible quantities in the waters of the Thames at Kingston, even though the lock at Teddington intercepts the upward progress of the tidal wave; and certainly the water of that river opposite to Chelsea bears strong evidence of the influence of the sea water upon its chemical composition. It will, therefore, be necessary to draw the waters intended to be distributed in any large town from a river, only from those parts of its hydrographical basin which are above the range of the tide; unless the volume of fresh water, and its velocity, should be such as effectually to overpower the tendency of the sea water to flow inland. Even in the latter case it will be found advisable to place the immediate source of supply upon the portions of the stream wherein the upland waters are able to maintain a counter-current to the flood tide, as they will certainly be fresher and purer than those of the mid-stream; provided always, that no local sources of impurity should exist. Indeed the influence of local causes of disturbance is sufficiently great to render extreme caution necessary, either in rejecting or adopting a source of water supply from a river; and it is worthy of remark that the practical pathological effects of even a slightly brackish water are not by any means so dangerous to the populations constantly using them as they have been said to be, or as they unquestionably are to strangers using them for the first time. Thus, the brackish waters of the Maas are constantly used by the inhabitants of Rotterdam, after simply undergoing a mechanical filtration; and, although they have a decidedly marked diuretic action upon strangers, they do not so affect the inhabitants of the town, in ordinary seasons at least. It appears, in fact, that the human



constitution can adapt itself to many extraordinary circumstances; but evidently it is not desirable to tax its capabilities of this description, or to use an inferior water instead of a better one, if the latter can, by any reasonable outlay, be obtained.

222. Even the best, and chemically purest, river waters are so disposed to receive, and carry forward, the light earths over which their contributing streams have flowed, especially during the rainy season, that it becomes almost always necessary to adopt precautions for the purpose of securing the deposition, or the separation, of the solid matters they may hold in suspension. In almost all cases, therefore, subsiding reservoirs, or filtering beds, are essential parts of the works for the distribution of river waters; and, as they are equally necessary when the water to be supplied is derived from the collection of surface drainage, the following remarks must be considered to apply to both sources of supply, although of course the applicability of any particular system of filtration will depend greatly upon local considerations of efficiency, or economy.

223. When the rivers from which the supply is to be derived are much charged with suspended matters, it is necessary to construct both subsiding and filtering reservoirs. The dimensions of the former must depend upon the state of mechanical division of the extraneous matters, and upon their specific gravities; for evidently the finer and lighter they are, the longer time will they require to separate themselves from the water. A total absence of current, or of agitation, is an essential condition for the efficient action of a settling reservoir; and in order to attain both that absence, and the perfect separation of the suspended matters, it appears to be advisable to make the reservoirs of sufficient dimen-

sions to hold the maximum supply to be provided for three days' consumption. The dimensions of the settling reservoirs of the New River Company were larger than those which would have been required in accordance with this rule; yet the waters leaving them were, at certain seasons of the year, notably impure. It appears, therefore, that river waters, especially when they flow over soluble or easily disintegrated soils, or over lands covered with vegetation, natural or artificial, cannot part with their extraneous matters by the mere deposition which takes place within the time practically attainable; and certainly, in the case of the New River above referred to, the mechanical deposition effected in the reservoirs was not sufficient to ensure the absence of organic impurity which ought to characterise the water supply for a large town. In such cases filtration is indispensable, nor can the result of the experiment recently tried at the Woolwich and Plumstead Works be considered to invalidate this opinion, or to prove that any chemical action applied in a settling reservoir would be capable of purifying the waters to the necessary degree. The fact is, that the nature of the extraneous impurities in a water, whether taken up during its flow over the surface, or during its passage through the ground, is exposed to such strange variations, that the mode of chemical treatment would require to be varied almost day by day; and, moreover, the cost of such a system would be enormous, if carried out on a large scale, and in an efficient manner. Practically, then, the only mode of purifying waters, containing matters in a fine state of mechanical subdivision, is to pass them through certain porous substances which should be able to arrest those matters.

224. In filtration the action of the intercepting material may be either chemical, or purely mechanical; but

the expense of carrying into effect any such chemical action is so great that it never can be applied to the large quantities of water required for a town supply. Hitherto no ingredient has been discovered which possesses the same powers for removing the organic impurities of a water as those of animal charcoal; but as it is necessary that the water to be filtered through it should previously have been cleared from the grosser particles in suspension, by being passed through a coarser description of filter, and that subsequently the water should again pass through some other filtering medium, in order to ensure its freedom from any particles of charcoal, we may safely consider that so complicated a process cannot be applied otherwise than for personal or domestic purposes. Indeed, a supply taken from the more perfect mechanical filters, with as great rapidity as the latter can yield them, will in almost every case satisfy, not only the public demands, but also the real exigencies of the case.

225. There are several kinds of mechanical filters, of which the systems adopted by Mr. Thom at Paisley, by the engineers of the various London water-works, by the engineers of the Toulouse and Nottingham works, and that of the use of filtering slabs whether natural or artificial, are the most important. Of these the system adopted at Toulouse and Nottingham is the most economical, when the bed of the river is suitable for its application. It consists in the formation of filter tunnels or drains in the sands upon the banks of the stream; and the water which finds its way into these drains becomes purified by the detention of the adventitious matters in the bed of the river from which it is washed away by the action of the stream. If, however, the river should carry down much clay, these tunnels would become choked in a very short time;

and again, if the sands should contain any salts of iron, lime, sulphur, or nitre, the waters will be affected by them. It rarely happens, indeed, that rivers flow over beds of pure silicious sand; and even when this is the case, the objections urged by Dr. Clark against the general application of this system are still valid. That gentleman noticed that near Glasgow, where many of these natural filters are in use, springs often rise into them from below, and bring in waters of a different quality from that of the river itself. The level of the tunnels being fixed, whilst that of the water varies according to the state of the river, the rate of filtration must vary also; so that in summer, when the consumption of water would be the greatest, the yield would in all probability be the least. These filter tunnels must also be exceedingly difficult to clean on account of the very nature of the materials of which they are formed; and their application must for the above reasons be confined to the localities which present the peculiar geological characteristics above shown to be requisite. At Nottingham, the system is said to answer well after many years' experience; at Toulouse its working has been far from satisfactory, especially in the case of the tunnels formed near the bed of the river, for in them a peculiar vegetation of aquatic plants was developed. At Perth a natural filter of the kind above described has sufficed for the supply of the town; and both at Lyons and at Tours the same system has been adopted. When the sands and gravels of the bed are of a nature fitted for the formation of the drains, it appears that the yield of water ranges between 300 and 400 gallons per foot superficial per working day of twenty-four hours.

226. The filter described by Mr. Thom as having been executed by himself at Paisley, appears to possess

some theoretical advantages over those offered by the other methods of artificial filtration; inasmuch as, from the fact that the last stratum of the filtering medium traversed is composed of a mixture of sand and charcoal, the effect it produces must be to a certain extent chemical as well as mechanical. This system may be described as follows, nearly in the words of Mr. Thom: "The site of the filters is on a level piece of ground excavated to the depth of from 6 to 8 feet, with impermeable retaining walls and bottom. The whole of the surface of the latter is then divided into drains 1 foot wide by 5 inches deep, by means of fire bricks laid on edge and covered with flat tiles, perforated with numerous small holes like those used in the floors of malt-kilns. These tiles are covered to the depth of 1 inch with clean gravel, about  $\frac{3}{8}$  of an inch in diameter; and upon this five other layers of gravel each of the same depth, but gradually diminishing in its dimensions until the last layer almost assumes the character of coarse sand, are laid. Over the gravel very clean, sharp, fine sand, 2 feet deep, is placed; and about 6 or 8 inches in thickness of this sand, near the top, is mixed with animal charcoal." Mr. Thom has latterly tried to substitute the pounded amygdaloidal rocks which occur in the neighbourhood of Paisley, for the charcoal, and it is said with considerable success, for the amygdaloids are stated to be capable of removing from the waters traces of peat in a manner nearly as effectual as if charcoal had been used. The explanation of this action is to be found in the affinity between the silicate of alumina and the vegetable and animal matters in combination with the water, which has been shown by Professor Way to be of a very powerful nature; but no experiments of a trustworthy nature upon the application of these chemically acting filtering

ingredients have yet been tried, upon a large scale at least; and certainly the difficulties which have been encountered in the attempts to remove the peat stains from the Rivington Pike waters of Liverpool ought to inspire some doubt with respect to the confident assertions of the propounders of theories upon the disinfecting powers of the amygdaloids or of the clays.

227. The system generally adopted by English engineers for town filtration comprehends the formation of settling reservoirs as almost indispensable adjuncts; but evidently the necessity for such works must depend upon the character of the river itself from which the water is derived. In the case of the Kent Water-works Company's establishment the settling reservoirs have been executed upon perhaps the largest scale of any of those around London; and this peculiarity may be accounted for by the fact that the Ravensbourne, from which the supply is taken, flowing as it does over a light and easily moved soil, is frequently charged with a large proportion of extraneous matters. The area of the settling reservoirs of this Company is about  $4\frac{1}{2}$  acres, whilst that of the filter beds themselves is about 3 acres; and the maximum rate of filtration is about 2,000,000 gallons per acre per day. Theoretically, and in districts of this character, the size of the subsiding reservoirs should be such as to allow of their holding a supply equal to four days' consumption; and, as a general rule, their depth is made about 13 or 14 feet. In the execution of these reservoirs precautions must be taken to prevent any injurious action upon the water; and the practice of the London engineers of forming the exposed slope of good gravel may be quoted as a very reasonable one. The filter beds should be placed as near to the settling reservoirs as possible, and the details of the most satisfactory works

of this description may be described as follows, nearly in the words of Mr. Quick : "The filtering materials consist usually of a layer of coarse gravel about 1 foot deep, in which are placed glazed stoneware drains; this is covered with a stratum of rough screened gravel about 9 inches deep; then with a stratum of finer gravel 6 inches deep; then with a stratum of still finer gravel 9 inches deep; over these strata of gravel a series of beds of sand gradually finer and finer in its texture are placed, having a total thickness of about 3 feet 6 inches; thus making the total depth of the filtering materials between 6 and 7 feet." The filters of the Lambeth, Chelsea, Southwark, and West Middlesex Companies are formed in this manner, and they are usually worked with a small head of water; but occasionally, as at the Kent water-works, the thickness of the filtering materials is reduced to as little as 4 feet 6 inches, whilst the working head of water is made 4 feet, instead of 2 feet as usual. Practical engineers differ in their opinions as to the merits of the respective systems; but the experiments of M. Darcy prove that for filtering materials of the same nature, the rapidity with which the water passes will be proportional to the head of water producing pressure, and that therefore there is a greater chance of effective filtration when the depth of the sand, &c. is increased. Moreover, as waters tend to purify themselves by the oxidation which takes place when they are exposed over large surfaces of small depths, their quality must likewise be more likely to be improved when the head upon the filter is small. The degree of purity of the water under consideration will, however, modify any abstract reasoning upon this subject.

228. At Southampton a very awkward attempt has been made to apply a system of mechanical filtration,

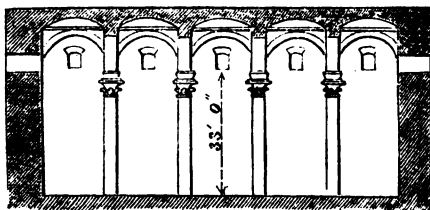
which, if it had been properly executed, might advantageously have replaced the more costly and more roomy systems usually adopted. It consisted in the use of—1, a layer of Ransome's artificial filtering slabs on which were placed, 2, a layer of gravel, and, 3, a layer of sand; the water passing through these materials *per ascensum*. This arrangement was precisely the reverse of the one which should have existed, because not only was it absurd to make the foulest water pass at once through the filtering medium the most difficult to clean, but it was a mistake to leave the filtered water exposed in the manner here adopted. It must always be borne in mind that a filtering medium becomes choked with a rapidity greater in the exact proportion of its power of retaining mechanical impurities; and that, therefore, the surface most exposed to those impurities must be easily visited and cleaned. Had the water at Southampton passed through the sand and gravel before passing through the filter slabs, and had it been withdrawn from beneath the latter, instead of being allowed to stand over them, there can be no doubt but that the quality of the waters would have been improved, and that the working of the filters would have been less exposed to danger. The practical result of the experiment at Southampton has been, however, to prove that with a working head of 4 feet, the Ransome's slabs, covered with 9 inches of sand, and 9 inches of gravel gradually increasing in coarseness, are able to yield as much as 100 gallons per foot superficial per day. The yield of the ordinary London filters varies between 40 and 50 gallons per foot superficial per day; so that the Ransome's filters would produce an economy not only of depth, but of area, of excavation.

229. Of late years there has been a tendency on the part of the engineers connected with English Water

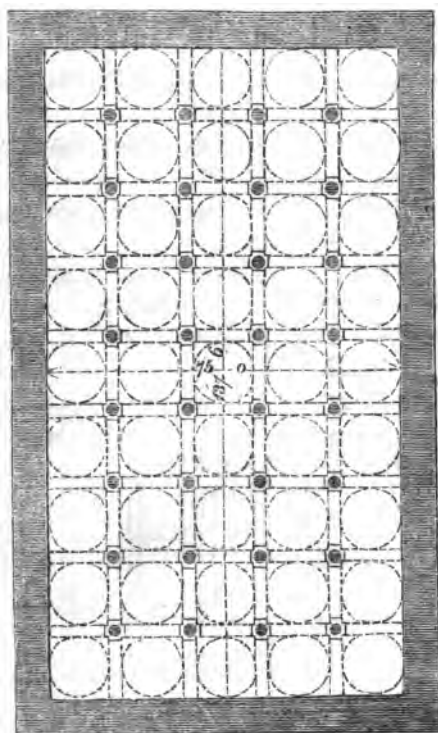


works Companies to suppress the storage reservoirs into which filtered waters were passed, and to trust entirely to the powers of machinery to meet the varying demands of a town consumption. Thus, the Kent Water-works and the East London Water-works Companies have materially diminished their storage capacity. The majority of the London Companies, however, have recently incurred very serious outlay in the construction of these buildings; and by recent parliamentary enactments it has been provided that they shall be covered. A great deal of skill has been displayed in the manner in which the various Companies have solved the problem thus set before them; but really no great advance has been made upon the systems adopted by the Roman or Byzantine engineers, allowing of course for the differences between the ancient and the modern modes of distribution, and for the different states of the metallurgic arts in the ancient and modern worlds. The Reservoirs at Puteoli and at Constantinople, represented in Plates 1 and 2, may indeed fairly be considered to have served as models for the New River, or the Plumstead, reservoirs; and the only material difference to be found between the Roman and the English structures is the one connected with the depth of water. In fact, the ancient engineers used their reservoirs as stores, and therefore great depth was required to ensure their cubical capacity; the modern English engineers rarely use their reservoirs for any other purpose than to compensate for the irregularity in the action of their pumping machinery, or to guard against any temporary accidents; and as they usually make the supply mains communicate with the reservoirs, it is essential that the head of water in the latter should only vary within a very limited range. A depth of water of about 14 feet

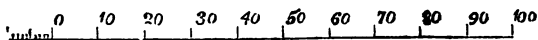
# RESERVOIR AT CONSTANTINOPLE

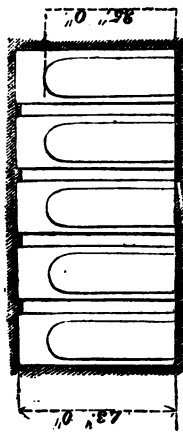


SECTION



PLAN

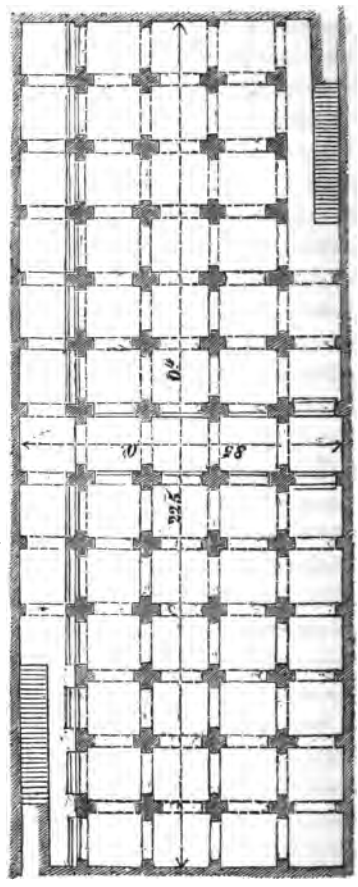




PISCINA ADMIRABILIS

AT

PUZZUOLI.



above the outlet is considered to be the maximum which it is advisable to adopt, especially when what is called the *constant service* is used. Local considerations of economy must regulate the choice of the materials to be employed; but it is essential, under any circumstances, that no materials should be admitted which would be likely to produce any chemical action upon the waters exposed to them. Thus at Paris, some small reservoirs have been entirely formed in hydraulic lime concrete, but if the waters to be kept in such structures should themselves contain an excess of carbonic acid, they would take up so much lime as to materially increase in hardness. It is for this reason that the sandstones, the hard-burnt bricks, and the argillo-calcareous cements are almost exclusively used in the construction of reservoirs; and it would even appear that there are objections to covering such structures with wooden roofs. The essential conditions to be observed in the formation of reservoirs, especially near towns, are in fact, that the temperature and the mechanical and chemical purity of the water should not be liable to be affected by accidental or adventitious circumstances; and therefore the materials of which they are formed must be insoluble and non-conducting. Open reservoirs are usually formed in country districts of England, at the rate of about £600 per million gallons stored; but the cost of the covered reservoir erected lately at Croydon, under the supervision of the officers of the late General Board of Health, was not less than £4000 per million gallons.

230. It may be necessary here to state that, in many cases where the water for a town supply is pumped directly into the distributing mains, a storage reservoir is still formed to receive the excess of water beyond that which is drawn off for household purposes. These

reservoirs become, in fact, regulating reservoirs; for their use is to store a sufficient supply for the period when the engines are not at work, and to provide against any minor accidents. The principal danger attending this system of direct pumping, arises from the frequent hydraulic shocks to which the mains must be exposed, from the opening and shutting of the house services; but this danger may be obviated to a great extent by laying secondary mains, called *riders*, near the leading ones, and by connecting the house services with the riders. Especial precautions must be taken to ensure the regularity of the flow of the water as it leaves the air-vessel of the pumping engine. In spite of all such precautions, however, the flow of the water in the upper portions of the mains must always be exposed to fluctuations of a very irregular nature; especially when the pipes are always under charge, and the consumption takes place directly from them, on what is called the constant delivery system. In some of the London Water Works, and at Hamburg, Amsterdam, &c., stand pipes have been used for the purpose of regulating the flow of the water pumped into the mains without the intervention of service reservoirs; but this course is certainly objectionable, on the score that when it is adopted all the water must be raised to the maximum height; whereas, when the water flows past the riders to the regulating reservoirs, the pressure upon the mains is partially relieved by the house consumption. The use of stand pipes is, indeed, rapidly being abandoned; though unquestionably there are positions in which it would be more economical to erect them than to form elevated storage reservoirs.

231. When it is decided that storage reservoirs shall be formed, their dimensions must be regulated,

firstly by the amount of the local consumption, and secondly by the nature and power of the steam or other machinery employed. If this machinery should be liable to interruptions in its action, or if the source of supply should itself be exposed to irregularities (as in the case of a tidal river, or of one in which freshets occur), it is necessary to make the reservoir of a capacity sufficient to ensure the delivery of water during the periods of interruption. Should the configuration of the country be favourable to the construction of these structures, they may be made so as to hold about three days' supply, in climates like those of the south of England. But from the necessarily expensive nature of these works, it is rarely that they can be executed of these dimensions, and in the greatest number of cases it will be found sufficient to make the reservoir of adequate capacity to supply the consumption of water during the hours that the engine may not be at work, or to enable it to raise the water by an equable effort during the working hours. For this purpose a storage reservoir, able to hold about one quarter of a maximum day's consumption, will be all that is usually required. It will, however, be necessary to provide duplicate engines, or at least to have a sufficient number of duplicate parts in constant readiness, in order to be able to repair any accident at the slightest notice, when the dimensions of the storage reservoir are confined within the above-cited limits. It is true that the supply will, to a certain extent, be liable to be interrupted; but, on the other hand, reservoirs of dimensions so ascertained, could be covered easily and economically.

232. In some French water works, as at Toulouse, and the old establishment of the Pont Rouge near Havre, the water is raised into a tank placed imme-

diately over the engine ; the tank thus serving, in fact, as the upper portion of a stand pipe, or as an air vessel, to discharge any air raised with the water, and at the same time as a distributing reservoir. Over a water-wheel, such as the wheel at Toulouse, this arrangement may present some advantages, provided, of course, that the machinery itself be not of a nature exposed to accidents, or to require frequent repairs. But unless such a tank can be made of considerable dimensions, or unless it be large enough to allow of its acting as a regulating reservoir, it must be evident that the mains could only be charged so long as the machinery is working.

233. The following additional practical observations may be made with respect to the execution of service reservoirs, of whatsoever description they may be. The positions of the inlet and of the outlet pipes must be arranged in such wise as to ensure a constant flow through the body of the water in the reservoir ; and precautions must be taken to keep back any impurities which might accidentally be introduced, by either forming depositing wells under the inlet pipes, or by placing gratings, or strainers, over the heads of the outlet pipes. A valve pipe must be formed, and if possible, it would be desirable that both the inlet and outlet pipes should pass through it, in order to secure greater facilities for the examination and repairs of the valves. Overflow pipes, waste wears, or other provisions must be made to regulate the height of the water ; scouring or cleansing pits must be formed, and they must have discharge pipes placed at such points as to allow the whole of the water to be drawn off if required ; and means of access to the bottom of the reservoir must also be provided. It is essential that the outlet pipe should be placed at such a level as

to retain a certain depth of water over the bottom, excepting when the scouring pits and their outlets are used. The object of this arrangement is to secure a more effectual deposition of the mechanical impurities of the waters.

## CONDUIT OR SUPPLY MAIN.

234. In most cases the water for a town supply has to be led from a considerable distance to the place of distribution, and as this operation may be, and often is, effected after filtration, it has been thought advisable to discuss the mode of effecting the latter process previously to the examination of the methods usually adopted for the execution of the main conduit. These methods are naturally dependent upon the character of the country over which the water has to be carried, and also to some extent upon the nature of the building materials at command. They may, however, be very conveniently considered to be ranged under the following general heads, viz. : open cuts in earthwork, masonry aqueducts, and pipe conduits, whether of metal, stone, or earthenware.

235. Open cuts are objectionable when the water has already been filtered near the source of supply, because there is a probability that the water may contract atmospheric impurities, or at least be affected by the temperature of the air. In the neighbourhood of large towns the former inconvenience frequently becomes of serious importance ; so much so, that in most countries the branches of the administration charged with the protection of the public health have invariably insisted that the water channels should be covered. In the previous portions of this work the various formulæ adopted for ascertaining the conditions of flow in open cuts have been alluded to (vol. i. §§ 40 to 46) ; but perhaps



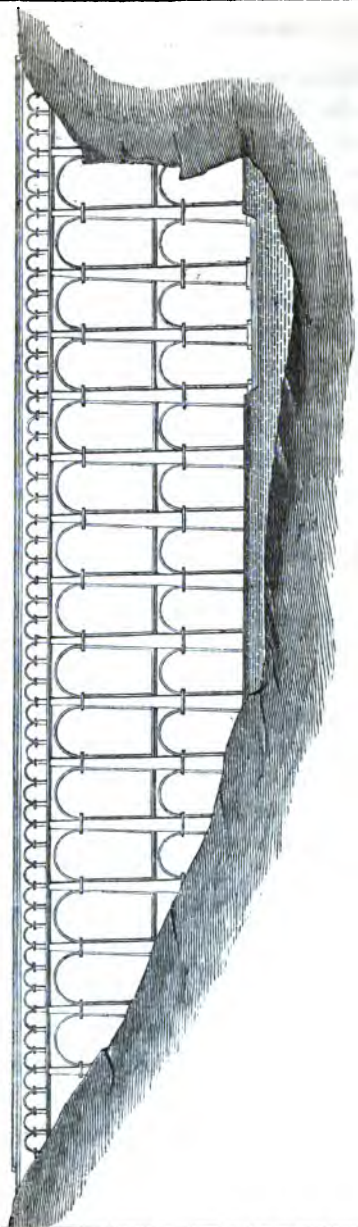
it may save trouble to state here that the engineers of the irrigation department of the Madras Residency, who have certainly had opportunities of applying the theoretical reasoning of European hydraulicians on a very large scale, have adopted as the basis of their tables for calculating the velocity and discharge of cuts, or canals, the formula derived from Buat and Neville,

$$v = \frac{88.51(r^{\frac{1}{2}} - .03)}{(\frac{l}{s})^{\frac{1}{2}} - \text{hyp. log}(\frac{l}{s} + 1.6)} - .84(r^{\frac{1}{2}} - .03)$$

in which  $v$  = the velocity of feet per second;  $r$  = the hydraulic mean depth;  $l$  = the length of the cut, and  $s$  the total fall, so that  $(\frac{l}{s})^{\frac{1}{2}} - \text{hyp. log}(\frac{l}{s} + 1.6)$  gives the ratio of the slope, or inclination of the channel. Captain Stoddard has drawn up an elaborate set of tables based upon this formula, which might very advantageously be reproduced in England, as they are rather more easily applied than the elaborate calculation contained in Mr. Neville's Hydraulic Tables (Weale, Lond. 1853). The last-named work must, however, be consulted by those who are desirous of studying thoroughly the important subject upon which it treats. Mr. Beardmore, in his Practical Tables, however, gives a simple and very easily applied rule for ascertaining the velocities and discharges of arterial drains, cuts, &c., and has given the results when the slopes are made, as they usually are, in earthwork channels of 2 base to 1 rise. His rule is, "to multiply the hydraulic mean depth in feet (which is ascertained by dividing the border into the area), by twice the fall in feet per mile; take the square root of the product and multiply it by 55; the result is the mean velocity of the stream in feet per minute; this again multiplied by the sectional area in square feet, gives the discharge in cubic feet per minute."

236. In consequence partly of the difficulty of protecting the water from contamination in open cuts, and partly from the tendency of the stream to wash away the banks, it is usual to lead water for town supplies in masonry channels. The Romans, whose practice in this respect may still be advantageously studied by the moderns, seem to have established as a rule that, wherever it was possible so to do, the top of the masonry vault should be kept at least 2 feet below the ground : in order, no doubt, to prevent any injurious action through the changes of atmospheric temperature ; and even when the aqueduct was raised above the level of the country, it was still covered with  $2\frac{1}{2}$  feet in thickness of earth. So long as the water is maintained in motion, this protection seems to be sufficient in the majority of instances, of Western Europe at least ; but in the recently constructed aqueduct of the Croton Water Works, the depth of the protecting coat has been made 4 feet. It is, however, to be observed, that the dimensions of masonry channels are affected by many considerations which render the application of strictly logical rules to them almost impossible. For, in the first place, they must be made of sufficient size to allow the passage of the workmen employed to examine and clean them ; in the second place, the nature of the formations traversed, and of the building materials employed, must at times, render necessary corresponding precautions, or modifications from any original type. As a general rule, the width of subterraneous aqueducts is made about 3 feet 6 inches, with a height, from floor to underside of key, of 7 feet : but these limits must vary according to the quantity of water to be conveyed. If the foundations should be naturally good, it is not necessary to

*AQUEDUCT OF ROQUEFAVOUR.*

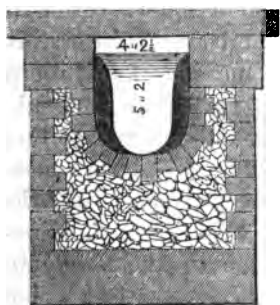


0 100 200 300 400 500 feet.

make the masonry of the floor more than from 13 to 14 inches in thickness; the side walls should be from 1 foot 10 inches, to 2 feet 3 inches thick; and the arched covering 14 inches thick at the key, if the superincumbent weight should not require a greater thickness. In the case of the Croton aqueduct, the thickness of the solid masonry which supports the conduit over valleys, is made somewhat greater than that of the aqueduct itself immediately below the floor-line, and a slight batter is given on both sides. The American engineers, in fact, seem to have used solid masonry foundations for their conduit, rather than earthwork embankments; nor did they begin to arch their substructure till its height became at least 20 or 30 feet, measuring from the valley to the top water-line. Like the Romans, the engineers of New York formed, moreover, a series of wells on the line of their conduit, to allow the deposition of extraneous matters which might find their way into the stream: and visiting shafts and air funnels were also placed from distance to distance upon the line of its axis.

237. Masonry conduits, such as are above described, have no doubt some advantages over pipes, amongst which may especially be cited the fact, that the earthy salts contained in the water, and which are sure to be deposited in course of time, are not so likely to produce injurious effects upon the conduits as they would do upon the pipes. The precipitation of the salts takes place, in fact, in the open air, and at an earlier period of the flow; and it must evidently be more easy to cleanse and repair such conduits, than it can be to perform the same operation upon pipes buried in the ground. On the other hand, it is evident that the construction of small masonry

conduits is, generally speaking, more costly than would be the use of metal pipes large enough to discharge the same volume of water; so that eventually the choice of the particular mode of conduit must depend almost exclusively upon local considerations; for motives of economy may often outweigh those derived from the theoretical advantage above cited. As an illustration of the extent to which the deposi-

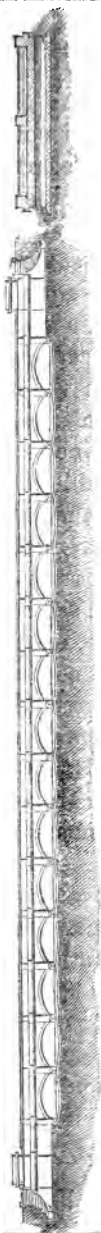


tion of the earthy salts may interfere with and contract the efficient area of a water-course, the accompanying sketch of the transverse section of the conduit upon the celebrated aqueduct of the Pont du Gard, is added. The portion shaded of a darker colour, round the water-course represents the deposit of calcareous matter which has gradually accumu-

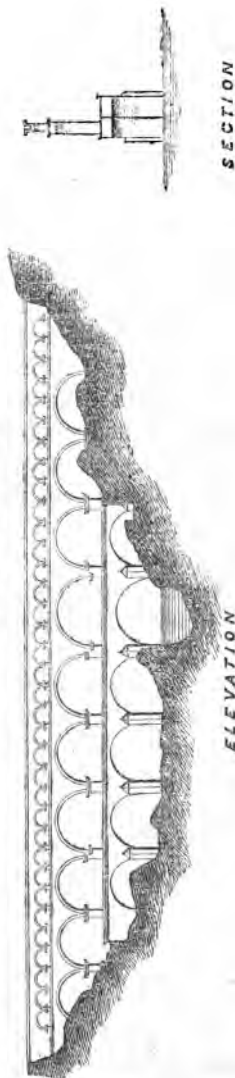
lated through the precipitation of the salts contained in the water, although great pains had been taken originally to ensure its purity. It was, indeed, the dread of the deposit from the waters of the Durance, which induced M. de Montricher to adopt the mode of conducting them to Marseille, which he finally did; and he was induced by the same motive to construct that splendid folly the aqueduct of Roquefavour. At the Liverpool Water-works Mr. Hawksley adopted the less showy system of subterranean pipes, which, it may be added, is usually followed by English engineers; for, working as they almost always do for commercial companies, they are not often allowed to indulge the fancy for erecting comparatively useless monuments.

# SOLANI AQUEDUCT (ELEVATION)

SECTION



## PONT DU GARD



ELEVATION

SECTION



238. In the case of the Romans, the choice of the modes of leading water from a distant source was far more limited than it is in that of modern engineers, from the fact of the inferior state of the metallurgic arts in the ancient world, compared with their state in modern times ; and even on the score of economy they were justified in erecting bridge aqueducts, which would, at the present day, expose their designers to severe criticism. In fact, the most serious difficulties which are likely to be encountered in the construction of conduits, are those arising from the occurrence of hills, or of deep valleys, in the line they ought to follow. The former, if of considerable elevation, will require to be traversed in tunnel ; the latter may be passed by bridge aqueducts, or by reversed siphons, in which the water descends from one reservoir through a pipe on one side, to remount to a second reservoir, through the continuation of the pipe, on the other, at a somewhat lower level ; from this second reservoir the conduit may be continued as before. As a general rule, the Romans effected the passage of such valleys by bridges, and the structures of this description which they have left behind them, are amongst the most strikingly beautiful relics of ancient art. Many of these monuments are of such colossal dimensions, and such singular elegance, that it would be unjust to mention them subsidiarily ; and the reader is, therefore, referred to the list of authors, who have treated of this special subject, which will be found in the Appendix, if he should desire to obtain further information on this branch of the subject. On the preceding page, however, an elevation and section of the celebrated Pont du Gard Aqueduct, is given in connection with the great Solani Aqueduct on the Ganges canal, erected by the engineers of the late

East India Company, and with the Roquefavour Aqueduct. These works are represented on the same scale, so that it will be easy to draw a comparison between their relative proportions; but it may here suffice to direct attention to the fact, that the modern work which is comparatively speaking, so little known, has an area of water-way, not less than eighty times that of the celebrated Roman example. The Roquefavour and the Croton Aqueducts are, it may be added, the most striking works of this description executed of late years.

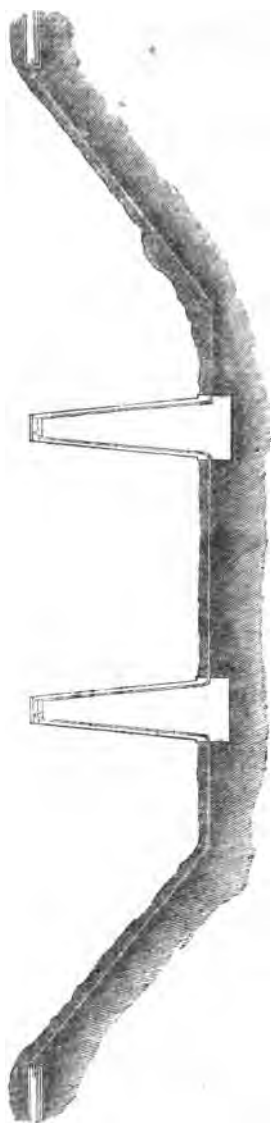
289. The practice of the Roman engineers in the construction of lofty aqueducts differed somewhat from that of modern engineers, in this respect, that the former resorted to several tiers of arches in cases where the latter would only use one tier. In countries exposed to volcanic action, the former system would appear to be preferable; but really the determining motive in such cases ought to be the economy of construction, which will be affected by so many local considerations that it would be dangerous to lay down any invariable rules on the subject. But whenever from motives of economy, or on account of the qualities of the water, it may be determined to erect masonry aqueducts of several tiers of arches, the proportions which ought to be observed between their different parts would appear to be that the height of the first tier should be equal to  $2\frac{1}{2}$  times the opening of the arches; the second tier should be made  $\frac{1}{3}$  less than the height of the first, and the third tier  $\frac{1}{4}$  less than the height of the second. In the construction of the celebrated aqueduct of Caserta, Vanvitelli neglected this æsthetical law, and he made the upper tier loftier than either of the lower ranges of arches, thus entirely destroying the artistic beauty of the work. But it is



hardly likely that, after the execution of the great siphon aqueducts of Liverpool and Glasgow, lofty structures of this description should be again erected; for the successful manner in which the immense reversed siphons upon the lines of water supply of those towns have been laid, appears to prove that there is no longer any excuse for incurring the outlay which must attend the erection of monumental structures such as were necessary in the times of the ancient Romans.

240. The Turkish engineers introduced into their European dominions a peculiar system of interrupted reversed siphons, if such an expression may be allowed, which it may be worth while to refer to here, on account at least of the light it throws upon the history of the development of hydraulic science. They were, it is supposed, induced to adopt this peculiar system for the purpose of saving, primarily, the outlay necessary for the construction of masonry bridges; and, secondarily, of diminishing the chances of rupture in the earthenware pipes of which the siphons were formed. The name for the system is "souterazici;" and it consists of earthen pipes, deriving their supply from an upper reservoir, thence descending a hill side, running along part of a valley, and mounting into an intermediate reservoir, supported upon piers of masonry, at a rather lower level than the first reservoir. From this second source of supply pipes were conducted down the opposite side of the pier, again along the valley, and successively into a third, or more, reservoirs, at gradually decreasing elevations, and so on to the opposite side of the valley. Evidently this was a very rude method of meeting the immediate difficulties of the case, and the loss of head upon the pipes, in consequence of the numerous bends, must have been considerable; but there was much ingenuity in the idea,

*TURKISH SOUTERAZICI.*



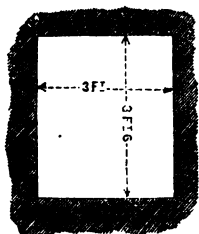
and perhaps it may be considered to indicate a better acquaintance with the laws of hydraulics than we are accustomed to attribute to the nation amongst whom the system arose. There is a large work of this description erected upon the ruins of one of the great bridge aqueducts of the neighbourhood of Constantinople, which had been destroyed during one of the numerous sieges of that town. Perhaps the best description of the Souterazici is to be found in General Andreossy's work upon "*Constantinople pendant les années 1812-26*;" or in Geniey's "*Essai sur les moyens de conduire et d'élever les eaux*;" to which the reader is referred for further details.

241. As was said above, the use of large metal pipes or mains, for the purpose of conveying water from the source of supply to the point of distribution, has of late years entirely superseded the necessity for the erection of aqueducts, excepting in the cases when the waters to be delivered are so highly charged with earthy salts as to render it dangerous to use pipes. The laws which affect the flow of the water in such mains have been partially discussed (in vol. i. §§ 36, 37, 39), and they will be examined more in detail hereafter, in the portion of this chapter wherein the ordinary modes of house supply are described. For the present it may suffice to say, that the material usually employed for this purpose is cast iron; and mains of 42 inches in diameter have been made of this metal. Very great precautions must be observed in laying pipes of such enormous diameter, and in regulating the pressure at intermediate points of their length; whilst it is also necessary to provide self-acting valves, or hand-valves, easily closed, in order to obviate as far as possible the chances of a rupture in the mains. Upon the Liverpool Water Works, supplied by the great Rivington

Pike reservoirs, Mr. Hawkesley introduced some very skilfully devised machinery of this description; and in the Minutes of the Institution of Civil Engineers for 1859, will be found a tolerably clear account of the valves and pressure regulators used upon the Melbourne Gravitation Water Works. It is important also to observe that the pipes leading from a distant source of supply to a distributing reservoir, must be placed (in fact, like all those required for a town distribution,) at such a depth from the surface, as to ensure their being beyond the limits of the effects of atmospheric variations of temperature. In England, a depth of four feet is sufficient for this purpose; but both in extreme northern and southern latitudes, it is necessary to descend considerably lower. In some portions of the distance between the ends of the mains it may likewise be advisable to insert double lines of pipes, and to make occasional connections between the two, in order that, in case of repairs to either of them, the flow may be maintained through the other.

242. As it is often necessary, in the course of executing the works required, either for an open masonry or a close pipe track, to pass certain mountain spurs in tunnel, it may be advisable to observe that the dimensions and form to be given to such tunnels must necessarily be regulated (so far as their minima are concerned) by the practical consideration that the workmen must be able to use freely the various implements of their trade, and to push to the extraction pits the materials disengaged during their operations. The nature of the rock traversed will also affect the sectional area of the excavation; for if it be of a nature to render lining upon the top and sides indispensable, as well as for the water channel itself, the dimensions of the cross section must evidently be increased. A

miner can work with tolerable efficiency in a heading of the size represented in the margin; but it must be considered as the minimum in all cases, because the

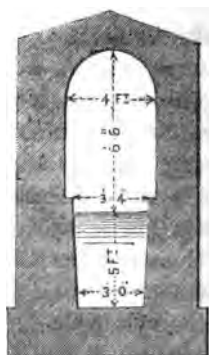
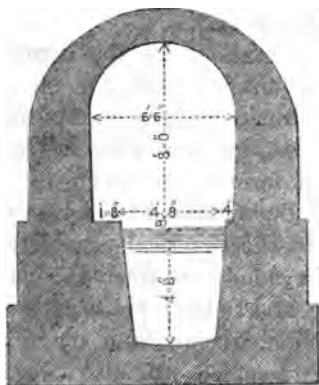


constrained position the workman would be obliged to assume in it would prevent his employing the whole of his useful power, and if the dimensions of the heading were made less than those indicated, the workman would hardly be able to move forward without even any impediment. It is also important that

the tunnel should be made sufficiently large to allow of its being easily visited and repaired. A very good example of a tunnel for receiving a conduit is offered in the *Aqueduc de Ceinture* of Paris, represented in figs. 1 and 2; for the dimensions adopted have been very

Fig. No. 1.

Fig. No. 2.



carefully calculated, in order to ensure the greatest efficiency, at the same time that they are as nearly as possible in accordance with the laws of economy. The

*Aqueduc de Ceinture* runs round the northern part of Paris, and from it all the mains for the supply of that portion of the town derive their supply. It is about  $1\frac{6}{10}$  of a mile in length, and has a total fall of only 4 inches, so that the flow of the water takes place simply in consequence of the difference of level caused by the withdrawal of the water through the various pipes branching from it. The section of the larger tunnel has naturally, under these circumstances, been made larger than is absolutely necessary for the mere purposes of easy execution and repair; but the small tunnel is as near to the dimensions theoretically required for those purposes as possible. This smaller tunnel was executed upon the embranchment of the *Aqueduc de Ceinture*, formed for the purpose of supplying the *Quartier St. Laurent*.

## PUMPING MACHINERY.

243. The various discussions of the previous part of this section have been made upon the supposition that the water is obtainable in such positions as to allow of its flowing by its own gravity to the place of distribution; but as it often happens that the source of supply is situated at a lower level than that place, it becomes under such circumstances necessary to employ some mechanical agent to raise the water. For the purposes of a town supply, the choice of the peculiar agent is practically limited to either steam or water power, according to the local circumstances of the town under consideration; and in both cases the motive power must be applied to pumps, because they alone of the various descriptions of intermediate machinery can force the water to the height and to the distance it is generally required to overcome in these cases.

244. Evidently it would be preferable to adopt water

power, wherever it exists naturally of sufficient extent, and of a sufficiently permanent character, because it costs very little for the daily working, or in fact hardly anything beyond the first outlay for the machinery and for the ordinary repairs. Steam power, on the other hand, requires a constant outlay for coals, and also gives rise to a more continuous and expensive outlay for repairs, maintenance, and attendance. But it rarely happens that such a water power is to be met with in the neighbourhood of large towns; and in the majority of cases even wherein it exists, it is found that the streams creating the motive power are so exposed to interruptions in their flow, from ice, floods, or droughts, that they can seldom be used for the purposes of effecting a service in which regularity of action is a matter of such serious importance. The determining motives for the choice must then depend upon the cost of the maintenance of steam power, and the interruptions to which the water power may be exposed, supposing it to exist. If these interruptions should not be of serious duration, they may be obviated by the construction of service reservoirs at the summit level of the distribution; but, of course, the expense of the construction and maintenance of these reservoirs must be taken into account in the comparative estimates. The problem to be solved in all such cases is, in fact, how to raise within a given time the greatest quantity of water which may be required, at the least possible expense, not only for the moment, but eventually.

245. In estimating the power to be provided, it is necessary to take into account the weight to be raised; the height, or dead lift, to be overcome; and the various causes of retardation of flow in the pumping main, arising either from the friction of the water upon the sides of the pipes, or from any change in their direction,

whether in a horizontal or a vertical direction. These last-named causes of diminished power will be discussed hereafter ; but practically they are considered to be met by allowing for an extra dead lift of 12 feet per mile of the conducting pipes between the engine and the reservoir, unless any very extraordinary vertical bends should occur. For instance, let it be supposed that 1000 gallons per minute are required to be raised to a nett height of 120 feet above the lowest clack of the pumps, or the water-line in the well, and to be discharged at the distance of  $2\frac{1}{2}$  miles. Then, as a gallon weighs 10lb. avoirdupois, the calculation would become in round numbers,  $10,000 \times (120 + 30) = 1,500,000$ , the moment of resistance. Now, as a horse-power is considered to be equal to 33,000lb. raised 1 foot high per minute, theoretically the power should be  $1,500,000 \div 33,000 = 45.46$  horse-power. But a steam-engine rarely works up to the nominal power, and a water-wheel falls short, even to a greater extent, of producing the effect calculated upon ; so that in cases where the former is to be used, it becomes necessary to affect the theoretical result by a co-efficient of 0.85 ; and where the latter is used, by a co-efficient of 0.75, for the most perfect description even of water-wheel, and during the period of its being in perfect working condition. In order, therefore, to perform the duty above specified, it would be necessary to provide a steam-engine of about 53.5 horse-power ; or a water-wheel of about 60.7 horse-power, nominal.

246. The towns of Philadelphia and Richmond, in the United States, and of Toulouse, in France, are, amongst others, supplied by means of water-wheels, all under-shot. Of these, the wheels at the Fairmount Water Works, Philadelphia, are the most remarkable, on account of the volume of water they are designed



to lift. This was not less than 10,000,000 gallons per day, with a dead lift of 92 feet, and discharging the water through cast-iron mains 16 inches diameter. The works were originally executed in 1822, and even at the present day it would appear that they are able to perform a working average of not less than 8,379,229 gallons delivered into the reservoirs. There are eight breast-wheels, 15 and 18 feet in diameter, with 15 feet length of bucket, and one Jouval turbine 7 feet diameter, giving motion to 9 double-action pumps having cylinders 16 inches in diameter, and a length of stroke of 5 feet; but the turbine and its pump are not yet in working order: the fall of water is  $7\frac{1}{2}$  feet, and the wheels make 13 revolutions per minute. At Richmond, there were two wheels 18 feet diameter, 10 feet on the face, with a 10 feet fall, working two pumps and raising 800,000 per day into reservoirs situated at 160 feet above the low-water line. At Toulouse, the wheels are 14 feet 5 inches diameter, 5 feet on the face, with a fall of 7 feet 6 inches; they are two in number, and raise about 896,000 gallons per day to a height of 67 feet above the water in the well.

247. The description of water-wheel to be employed must, of course, depend upon the conditions of the flow of water in the river producing the motive power; it may be under-shot, over-shot, or breast, according to the height of the fall, or the volume flowing through the sluices. Of the under-shot wheels, those constructed upon Poncelet's system with curved floats and working in a close concentric race, or channel, are the most economical, and yield the greatest effective power. With a fall of 5 feet, or under, they produce a dynamical action equal to 0.75 of the theoretical power employed; with greater falls this co-efficient descends to 0.60; but in the case of under-shot wheels with straight floats

the effective dynamical power rarely attains even the latter co-efficient, and they have, moreover, the serious inconvenience of being exposed to be rendered unserviceable with a much smaller amount of back-water than is able to stop the working of a Poncelet wheel.

248. Over-shot wheels produce a useful dynamical effect, which is sometimes as much as 0·80 of the power actually exerted upon them; but under the ordinary conditions of working, and with a velocity of the periphery of about 3 feet 6 inches, or 7 feet per second, the useful dynamical effect is only equal to from 0·75 to 0·70 of the power. This description of wheels requires that the supply of water should be uniform, and that directly the water has left the wheel it should flow away freely. At times these conditions can only be obtained with difficulty, and under such circumstances the breast-wheel is resorted to; because it can work under greater variations in the supply, and with a greater amount of backwater during times of flood than are admissible with over-shot wheels. If the breast-wheels be constructed with the best modern improvements, they will be able to produce a useful dynamical effect, which may safely be calculated at 0·75 of the power employed.

249. As was before mentioned, turbines have occasionally been employed for the purpose of raising water for the supply of towns; and they certainly possess the remarkable advantages of being able to work under almost any fall, and of producing useful effects, with a very wide range in the velocity of their revolutions. They are said to yield a dynamical effect varying from 0·70 to 0·75 of the power, and they may be employed in cases where no other description of water-wheel could possibly succeed. In England, the only known

application of the turbine to a town water supply is at Weymouth, where a machine of this description has lately been erected under the orders of Mr. Hawksley. The foreign engineers seem, however, to be more convinced of the advantages of this description of water-wheel than our English engineers generally are; and the principles of this class of machinery have been discussed both in France and in America, in a series of publications mentioned in the Appendix: very little of value upon the subject has been published in our own country.

250. In most of the large towns of England wherein it is necessary to employ mechanical power to raise the water, steam-engines are generally used, for the reasons before mentioned, or because the water power of the locality has been already appropriated. Until within a very recent period it was considered that when the power of the engine was required to exceed from 20 to 25 horses, the description of engine known as the Cornish engine was the most advantageous; but the results of the observations lately made upon the working of the double-action engines erected by Messrs. Simpson for the Chelsea and Lambeth Companies, and by Messrs. Bolton and Watts for the New River Company, would appear to re-open the controversy with respect to the merits of the various systems of pumping engines. Below the limits above mentioned there is, however, a decided advantage in using the most direct acting engines, both in respect to first cost and to subsequent working; or even in using small horizontal engines with fly-wheels, communicating motion to shafts bearing the pump-rods. In the case of the Cornish engines, or rather in any case wherein it may be necessary to raise large quantities of water to great heights, the most favourable conditions of movement in

the pumps are, that they should begin by raising the load rapidly ; and that when the first motion is perfectly determined, the effort used to move that load should be diminished progressively ; so that, in fact, the motive power shall cease to act before the piston shall arrive at the end of the stroke. This is effected, in the Cornish engines, by introducing steam at great pressure upon the piston, through large orifices ; the steam is then allowed to expand directly the inertia of the water has been overcome, and it has assumed an ascensional movement, which may be maintained by a very small additional effort. In the engines used for raising water from the Cornish mines themselves, the initial pressure of the steam is about from  $2\frac{1}{2}$  to 3 atmospheres ; the expansion begins at from  $\frac{1}{4}$  to  $\frac{1}{2}$  of the stroke of the piston ; and at the end of the stroke the pressure is not more than from  $\frac{1}{4}$  to  $\frac{1}{10}$  of an atmosphere. In small pumping engines, on the contrary, it is necessary that the action should be uniform ; and on this account it is advisable to divide the action in such a manner as to work three pumps, by means of cranks, forming with one another angles of  $120^\circ$  upon the same shaft.

251. In the great London Water-Works the style of engine usually adopted is the Cornish engine ; and it may be worth while to mention here, that in the East London Water-Works establishment the largest single machine of this description has been erected within a very few years, under the orders of Mr. C. Greaves. This engine has a cylinder of 100 inches in diameter, and 11 feet stroke, working a loaded pole of 4 feet 2 inches diameter with a velocity of 6 strokes per minute, and raising no less than 150 cubic feet of water in a stroke. But, as was said in the last paragraph, the experience of modern engineers appears to

lean in favour of the use of beam and fly-wheel engines ; and if all that is reported of the action of the machines erected for the New River and Lambeth Companies be correct, there would appear to be no doubt as to the superior efficiency of the principle upon which they are designed. The engines erected at the New River Head are of two kinds : four of them are double-cylinder engines, in which the high-pressure steam of the first cylinder acts expansively on the second, made by Messrs. Simpson and Co.; and the remaining two are single-cylinder engines, with a comparatively speaking small stroke, made by Messrs. Boulton and Watts. Many years since it was said that these machines were able to perform a duty equivalent to 98 million lb., raised one foot high, by the combustion of one cwt. of coal ; and now the duty is said to be even carried so high as 120 million lb. Unfortunately, the experiments from which these results were obtained were not made contradictorily ; and they must therefore be, for the present, received with caution. There is, however, one undoubted advantage possessed by the fly-wheel over the Cornish engines ; viz., that they are capable of working at very different rates of delivery. In a town supply this may often become a matter of serious importance, as the demand is subject to very unexpected variations of an accidental nature ; but again, it must be observed that the working details of the latest pumping engines, of whatsoever description they may be, have been so carefully adjusted that they are even used without any regulating reservoirs or the old-fashioned stand-pipes so generally erected at the beginning of this century, and that the drivers of the engines can easily meet almost all the variable conditions of the consumption.

## MAINS AND DISTRIBUTING PIPES.

252. Between the pumping station or the collecting reservoirs of a water supply, and the point where the distribution to the various parts of the town commences, the water flows through a simple pipe of an uniform sectional area; and, as far as possible, with a constant, uniform velocity. In its course through pipes generally, however, the flow of the water is retarded by a series of resistances, which practically may be resolved into those depending—1, upon the friction on the sides of the pipes; 2, the loss of velocity occasioned by the bends; 3, the loss arising from the changes of direction from the mains to the submains or branches, if any such should exist; and 4, the gurgitation which occurs at every interruption in the flow. These retarding influences will be examined in order.

253. The friction on the sides of pipes depends principally upon their diameters and lengths, and upon the head, or column of water upon the respective orifices of supply and discharge; and practically, this result is again modified by a co-efficient varying with the velocity of the water, and, if M. Dupuit's observations be correct, with the nature of the material of the pipe itself. For all practical purposes it may be sufficient to consider that the quantity of water flowing through a pipe of uniform diameter, receiving its water from a reservoir at a high level, and discharging it into another reservoir at a lower point, without any change in the direction of the pipes, may be ascertained by the formula

$Q = c\sqrt{\frac{H + \zeta - H'}{\lambda}} D^3$ ; in which  $Q$  = the quantity sought;  $\zeta$  = the difference of level between the extreme orifices;  $\lambda$  = the length of the pipe;  $H$  = the head

upon the upper, and  $H'$ , the head upon the lower orifice;  $D$  = the diameter of the pipe; and  $c$  = a coefficient to be derived from the following table :

Velocity per second. $c =$	2 in.	4 in.	8 in.	12 in.	15 in.	20 in.	78 in.
	15.06	17.22	18.83	19.50	19.84	20.07	20.79

and for any velocity beyond  $c = 21.043$ .

254. This formula, however, cannot be applied unless the velocity is previously known; and if this should not be ascertainable by actual observation, it may be calculated as follows:—make  $K = \frac{H + \zeta - H'}{\lambda}$ , in which the notation of the preceding section will be followed; then we should have, according to De Prony's formula, as given by Playfair

$$V = -1541131 + \sqrt{.023751 + 32806.6 \times \frac{DK}{4}}.$$

255. In practice the conditions usually met with are not so simple as those above supposed, and it therefore becomes necessary to adopt other methods of calculating the quantity discharged, as affected by the resistance, which methods may be described nearly as follows, in the words of D'Aubuisson, the author of the best practical and theoretical treatise on hydraulics to be found in any language. When water flows from a pipe, the vertical height of the fluid in the reservoir above the discharging orifice is called *the head*, and it is represented in all D'Aubuisson's observations by  $H$ . The velocity due to this head is, however, diminished by the friction upon the sides of the pipe; so that the portion of the head acting upon the discharging orifice, can only be represented by the height able to produce the observed velocity of discharge. If this velocity be

called  $v$ , the height producing it will be  $\frac{v^2}{2g}$ ; and  $H - \frac{v^2}{2g}$  will be the portion of the head destroyed in creating it; this portion, expressed in round numbers, is known as the "loss of head." He then continues to observe that, as the loss of head is caused mainly by the action of the sides of the pipes, it will be proportional to their length and to their contour. But in proportion as the section of the pipe increases, the resistance from friction on the sides will diminish, because it will be distributed over a greater number of fluid molecules, and will consequently affect each one, as well as the whole mass, to a less extent; the resistance from friction will, in fact, be in the inverse ratio of the sectional area of the pipe. The retardation, then, will be proportional to the square of the velocity, with an addition of a fraction of the simple velocity itself. It is also to be observed, that in the course of these observations, the pipes are always supposed to be full; for if they were not so, the flow of the water would be regulated by the laws which affect it in its passage through ordinary open culverts.

256. Then calling the length of the pipe  $L$ ; the sectional area  $S$ ; the wet contour  $C$ ; and the two co-efficients it is necessary to introduce  $a, b$ ; the expression of the resistance will become  $a \frac{C L}{S} (v^2 + b v)$ , and we should have  $H - \frac{v^2}{2g} = a \frac{C L}{S} (v^2 + b v)$ . It is then only necessary to ascertain the values of the co-efficients  $a, b$ , in order to apply the formula to ordinary purposes. Almost every author who has written upon this branch of the science of hydraulics, has attributed different values to them; so that great uncertainty is still attached to the correct solution of the



problem. But it appears that the formula and values given in Weisbach's *Mechanics* are sufficiently accurate for practice. That author calls the loss of head occasioned by the friction  $h_1$ , and confining his attention simply to the length and diameter of the pipes, he makes  $h_1 = \left(0.01482 + \frac{0.017963}{\sqrt{v}}\right) \frac{l}{d} \cdot \frac{v^2}{2g}$  feet. It is true,

Messrs. Provis and Peacock's experimental inquiries appear to indicate an important error, even in this estimate of the values of the respective co-efficients; but as the results obtained from their application are admitted to be always in excess of those rigorously wanted, it would certainly be advisable to adhere to them in designing any works for the distribution of water through pipes; because any imperfection in the manner of laying, or any sudden increase in the demand, might render necessary the supposed exaggeration of diameter they would lead to.

257. It is, perhaps, the more advisable to adopt formulæ which would lead to the use of pipes slightly in excess of those required to discharge, *at first*, the quantity of water assumed to be delivered; because in all pipes, as we have before seen, the effective diameter becomes reduced by the deposition of the salts contained in the water, or by the oxidation of the pipes themselves. Even in cases where the diameter of the main conduits has been rigorously calculated, it is customary to allow an additional  $\frac{1}{8}$ -inch, in order to counteract the effects of the incrustation.

258. The friction, and consequent loss of head, upon water flowing in pipes, is considerably increased by any changes in the direction of the pipes, whether horizontally or vertically; and this increase is found to be in a certain definite proportion dependent upon the ratio of the diameter of the tube to the radius of

curvature of its axis. Navier states that the formula,

$$h_1 = \frac{v^2}{2g} \left( 0.0039 \frac{1}{r} + 0.0186 \right) \frac{a}{r}$$

in which  $r$  = the radius of the curvature, and  $a$  = the development of the arc, will represent the loss of head thus occasioned. According to him, also, it would appear that  $h_1$  is proportional to the square of the mean velocity, and to the length of the arc; that it is a function of the radius of the arc, and independent of the diameter of the pipes; and that  $h_1$  decreases in proportion as  $r$  increases. It is usual to make  $r$  of the following dimensions, when it is desired to apply the above formula to the case of side mains branching off from a leading main;—

Diameter	2 to 3 in.	3 to 4 in.	6 inches	8 inches	10 in. and upwards.
Radius $r$	1 ft. 6 in.	1 ft. 8 in.	2 ft. 6 in.	3 ft. 6 in.	5 feet.

259. It is to be observed also, that the rate of delivery in pipes with vertical bends is affected by the accumulation of air at the summit of the bends themselves, and by the loss of that portion of the initial dynamical effort which is required to overcome the resistance of the column of water to be lifted on the lower side of the bend. The former of these inconveniences may be obviated, if required, by placing air-vessels at the top of the upper limb; the latter is overcome by accelerating the rate of flow in the pipe, immediately before the water arrives at the bend. But under any circumstances it is desirable that the pipes, in which there are any deviations from the straight line, should be kept constantly full, in order to prevent as much as possible the accumulation of air in them. In laying great lengths of leading mains, it is

customary to place the air-vessels, or the pressure regulators, upon the summits of the most important vertical bends.

260. The formula which expresses the conditions of the flow of water in a pipe of uniform diameter, and working under a constant pressure, ceases to be applicable when there is a series of side branches or of sub-mains, deriving their supply immediately from the principal one. During the course of the distribution, a difference in the volume of water passing through the pipes must necessarily arise from the mere fact, that a portion of the water will be drawn off by the side mains; and therefore, in the latter parts of their course, the supply mains must be proportionally diminished to the service they are designed to supply. But it may sometimes happen in practice, that the cost of new models for smaller pipes may be so great as to render it more economical to retain the original dimensions of the mains; so that this question of detail must be carefully considered in forming the comparative estimates of the various modes of effecting the supply. It is, however, always necessary, before deciding the dimensions of any main pipe, to take into account not only the absolute theoretical requirements of the case, but also the probability of any eventual increase in the supply which the mains may have to carry.

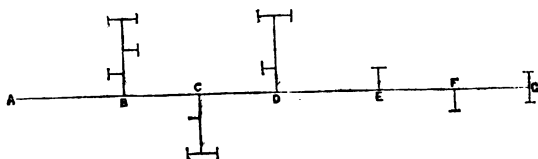
261. Mr. Hawksley stated that the method he adopted to ascertain the diameters to be given to the pipes laid down upon what is called the constant delivery system (in which the pipes are always under charge, and no cisterns are used), is to divide the length of the main in a street into portions of 200 yards each, and to assign to every such portion the quantity of water it would be likely to require, on the supposition that that quantity would be discharged in

four hours. He then allows for a loss of head equal to 4 feet in every 200 yards, and adopts, in calculating

the diameters to be given, the formula,  $\frac{1}{15} \sqrt{\frac{q^2 l}{h}} = d$ ,

in which  $q$  = the number of gallons;  $l$  = the length of the main in yards;  $h$  = the head in feet; and  $d$  = the diameter required, in inches. The system recommended by Claudel in his "Formules à l'Usage de l'Ingénieur," is, perhaps, more theoretically correct than the one thus recommended by Mr. Hawksley, although it is certainly more difficult, and more tedious in its application. It may be stated, as nearly as possible in the words of the original, as follows:—

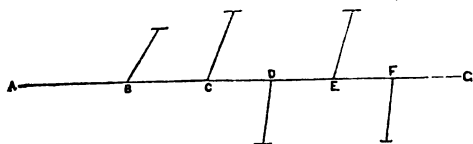
262. Case First. Let it be proposed to supply a district of a town by means of a pipe of uniform diameter throughout its length, and discharging the water through pipes constantly flowing; then the diameter of the pipe should be sufficient to ensure the delivery of the water from each opening at a slight distance above the points of discharge themselves at the extreme end of the district. This diameter is, for the purposes of calculation, assumed; and the loss of head for the distance between A and B is calculated in the usual way;



and this loss being deducted from the original head, will give the head acting effectively at B, which must be at least sufficient to ensure the delivery of the water from all the orifices upon the said branch B. The loss of head between B and C is ascertained in a

similar manner, it being observed that the quantity of water discharged by the main will be, of course, diminished by the quantity withdrawn by the branch B; and, as before, the head thus actually existing at C must be sufficient to ensure the supply of all the orifices upon the branch. Proceeding in this manner it will be seen whether the head upon the last division of the main will suffice to supply the demand upon it. If this should not be the case a larger diameter must be used, if the head cannot be increased; or if the head at the end should be in excess of that which is absolutely required, a smaller diameter may be adopted.

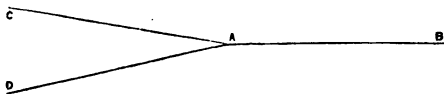
263. Case Second. Let it now be required to determine the diameter of a pipe receiving water from both ends, and supplying in its length certain orifices discharging definite quantities. In such a case it may happen that some of the orifices are supplied entirely from A; some entirely from B; whilst some, as D for instance, may derive their supply partially from one or from the other end, or it may be from both. Then the



diameter of the main, in either of the parts D A, D G, must be such that if D be supplied from both ends, the effective head at D and the consequent entry of water from both sides should be equal. It is necessary to proceed by approximation as in the last case, in order to ascertain whether this condition be or be not attained, and to assign some imaginary diameters to A and G; and after deducting the losses of head occasioned by the several branches B, C, E, F, the remain-

ing effective heads upon the respective portions of the main at D will be determined. Should those heads not be equal, the dimensions of the mains must be altered as the results obtained may indicate.

264. Case Third. Should the supply main derive its waters from two pipes whose delivery is known, and should it be desired to determine the diameter of the pipe from A to B, so as to ensure a particular distribution upon its length, the course to be followed may



be thus described. A certain approximate diameter is assigned to A B, and as the discharge is known and the difference of level between A and B is also supposed to be known, the effective head required to ensure the supposed conditions may easily be ascertained. If then the diameters of A C and A D be also supposed, as the volume supplied by them respectively is known, it will be easy to calculate the loss of their initial heads by the time the water arrives at A. The heads of the respective columns of water at this point must be equal, and sufficient when united to ensure the delivery supposed to take place between A and B; if the diameters of the several pipes should not be such as to ensure these conditions, they must be modified according to their excess or deficiency.

265. When the distribution takes place by means of a conduit of different diameters, it will be found that the system of calculation indicated in the first illustration will suffice to ascertain the required conditions; because the diameters of the pipes are constant between two successive openings, and the rate of delivery between those openings is also uniform. It is necessary,

however, in calculating the losses of head which occur, to allow for the differences introduced in the diameters of the respective portions of the main.

266. In carrying out the working details of any town distribution of water, it is necessary to observe numerous precautions, in order to protect the pipes from injury by external causes. In § 235, attention has been already called to the effect of variations of temperature in the atmosphere, and it may be interesting here to add that in such positions as Montreal or St. Petersburg, the water in pipes has been frozen even at six feet depth from the surface. It was generally supposed that the temperature of the water was at all times affected by the temperature of the ground in which the pipes were laid ; but from the experiments made by M. Girard (See his "*Mémoire sur la Pose des Conduites d'Eau dans la Ville de Paris*," 1831), which have been confirmed by subsequent observations in other countries, it would appear that at whatever temperature water may enter a pipe it will leave the pipe at precisely the same temperature, if the rate of flow be maintained constantly. In a municipal distribution of water it is impossible to secure this condition, for the consumption of water takes place in a very variable manner, according to the wants or to the habits of the population ; and it therefore is necessary to place the distributing mains beyond the possible action of frost. Moreover, in towns it is essential to place the mains at a sufficient depth from the surface to guarantee them from the vibrations in the soil of the roads produced by the traffic ; and also if gas should be used, precautions must be taken against contamination by the gas. A minimum depth of four feet will suffice to secure the former object, and the danger from the escape of gas is to some extent obviated by placing the water pipes

at a lower level than that of the gas pipes. It may be here added, that M. Girard found that the lineal dilatation of cast iron pipes was equal to 0·00000300228 of a foot for every additional degree of Fahrenheit, if they were free and in the open air; but that when the pipes were filled with water and buried in the ground the dilatation was considerably reduced. The pipes themselves under the latter conditions assumed temperatures which were functions of the difference of temperature of the surrounding media, but which were nearer to that of the ground, or denser medium, than to that of the water.

267. A very important precaution to be observed in the execution of a municipal water supply is, that what are technically called *dead ends* should be avoided, or in fact that there should be no portions of the mains in which the water should not flow freely. It is essential also to make every sub-main and if possible every house service, independent of the other portions of the distribution, in order that when repairs are required of a nature to render it necessary to shut off the water in any particular place, the interruption in the service may affect as few houses as possible. For the purpose of thus shutting off the water, *sluices*, or as they are sometimes very incorrectly called *hydrants*, are placed close to the embranchments of the sub-mains upon the principal ones; and these sluices have an occasional additional advantage from the power they confer of temporarily stopping the private distribution, if it should be required to concentrate the supply to any one place on the occasion of a fire or other accident. Small stop cocks are to be fixed at the junctions of the house services for similar purposes.

268. Fire plugs are placed in London at distances varying in the districts of each separate company; but



it appears that upon the average there is a fire plug to every ten houses, and in the New River district, perhaps the best organised of the older London Companies, there is a fire plug at every interval of 73 yards upon the services, and of 157 yards on the mains. In large towns also it is advisable to fix stand pipes at distances of about 500 yards for the supply of water carts. This branch of the public service is found to require a supply of about  $1\frac{1}{4}$  pint of water for every yard superficial, and for every time that the watering is performed. In our climate it appears that the streets thus require to be watered for 120 or 135 days in the year; and in summer it may frequently be necessary to water the roads twice in the day. Mr. Hawksley, however, adds to the observations usually made upon the consumption of water for roads, that the nature of their surfaces will materially affect the amount; and he assigns as the usual proportions one ton of water to every 600 square yards of macadamised roads, or to every 400 yards of paved ones. A considerable quantity of water is also used, in some English towns especially, to cleanse the sewers and drains; and it appears from Parliamentary returns that the proportion of the water thus supplied for street watering, fires, scouring sewers, &c. is about 2 per cent. of the total quantity. In continental cities, however, the proportion of water thus used, without directly entering into what may be called the private or the remunerative consumption, is far greater than it is with ourselves, for the bulk of the water supplied to the former is employed in the ornamental fountains, or the small *bornes fontaines* as the stand pipes which serve to clean the gutters or water-courses are called. The *bornes fontaines* in fact render great service in hot countries, and under certain developments of civilization; and as in all probability their

application in the cities of our own tropical possessions might be advantageous, a short description of them and of the system of distribution of which they form part is subjoined ; it is based upon the system actually applied in Paris.

269. There are several reservoirs established in the various quarters of Paris ; but in the day time, the water, instead of passing from the main feeders to them, is diverted into the sub-mains, and allowed to flow from a series of small stand-pipes into the street gutters ; at night these stand-pipes are closed, and then the water flows into the reservoirs, where it is stored for the supply of those parts of the town which are not immediately upon the lines of the principal mains. The *bornes fontaines* are at the charge of the municipality, and they flow during the summer months, at three separate intervals of one hour each, or three hours per day, discharging in that time 650 gallons of water ; in winter they only flow for two hours per day. Generally speaking they are placed at distances of about 410 feet, and wherever it is practicable they are placed at the culminating point of a gutter, so that the water may divide and enter the sewers as rapidly as possible after flowing in both directions. The necessity for this apparent waste of water arises from the fact that, in Paris, it is customary to discharge all household refuse, such as we consign to the dust-bin, into the street kennels, and therefore a copious flow of water is required to keep those kennels clear. Moreover, the flow of water from the fountains serves to cool the air in the close narrow streets of that town, in which the sun's rays are reverberated with singular intensity on account of the material used in the construction of the houses. It appears that more than half the total quantity of water brought into Paris is poured into the

kennels through these *bornes fontaines*, so that in fact the quantity left for private distribution must be very small indeed. As the gross average supply of Paris does not exceed twenty gallons per head per day, and in addition to the stand-pipes, the water columns, ornamental fountains, and trade consumptions have to be supplied from the same source with the private consumption, the latter cannot exceed, even if it attain, five gallons per head per day; and it is important to observe, when comparing the ultimate benefits of the systems respectively adopted in France and in England, in Paris or in London, that in the former no high service actually exists, and practically water is sold by the pail, whilst in the latter, water is obtainable at almost any reasonable elevation, and the price is so low as to induce, as was before said, rather a profligate waste of water.

270. Until within a very few years the supply of water to private consumers was effected in all countries upon what is now called "the intermittent system," that is to say, that the distribution took place under low pressures, and at stated intervals. In these cases the water was brought into the houses by lead pipes, branching upon the mains in the street, and leading to cisterns provided with ball-cocks, and waste, or overflow, pipes for the purposes of stopping the supply when the water had risen to a certain level in the cistern, or of carrying away any surplus quantity delivered; and the water was stored in these cisterns until used, or thence raised by the inhabitants of the houses by force-pumps to any greater altitude which they might require. The changes which have taken place in domestic habits of late years have, however, rendered it necessary to supply water even in the upper stories of dwelling-houses; and even upon

the intermittent delivery a great change in the height of the service had been forcibly introduced before the constant delivery system had been prominently brought before the public. Thus, in London itself the service was divided into the high and the low services, for which there were corresponding differences of charge. The "low service" was understood to mean that the water was delivered at a height not exceeding from six to nine feet above the level of the roadway in front of the house; whilst the "high service" was comprehended within a level of about thirty feet above the same level, and included every delivery above the six or nine feet before mentioned. Upon either the high or the low service, however, it is necessary to resort to the use of cisterns, so long as the delivery is intermittent; and as the first cost and the subsequent maintenance of the machinery and of the cisterns themselves is great, and the cleanliness of the cisterns requires constant attention, it is not surprising that earnest efforts should have been made to avoid the evils which certainly are attached to the intermittent delivery.

271. It was for this purpose that Mr. Hawksley introduced the system now generally known as "the constant delivery," in which the mains and service pipes are kept constantly full, under very great pressure, so that water can be drawn from them in any quantity, and at any level in the houses supplied. It will at once be perceived, that with such a mode of distribution there can be no occasion for the use of cisterns, and that the water would, with a few precautions, be kept in a state of purity which cannot be secured when it is stored in those receptacles. But it is essential also to observe, that in order to resist the hydraulic jar produced by abruptly closing the service pipes after withdrawing water, it is necessary to adopt a system of

internal distribution, and to introduce internal fittings which are often of a more expensive character than those which would suffice for a distribution upon the intermittent system. There is a more serious objection to the high pressure constant delivery, however, in this respect: that unless great precautions are taken, and a very strict supervision be exercised, a very enormous increase in the consumption of water will inevitably take place, as was previously observed in § 198. So seriously, indeed, has the consumption of water (or rather its waste, for it can never be fairly consumed,) increased in some towns, that it appears to be almost necessary to render the use of meters compulsory. In fact, as the ordinary charge for water is 6*d.* per 1000 gallons, the price is nearly the same as that charged for gas, and there can be no reason why a profligate waste of the one article should be tolerated, whilst that of the other is practically restrained. Unfortunately there is no satisfactory high pressure meter yet made, so that for the present a great deal of waste must be tolerated, if the constant delivery at high pressure be introduced. It may thus be unadvisable, even in a new work, to introduce the constant delivery; and it may also be utterly impossible, with any due regard to economy, to modify an old established work, in order to introduce that system, notwithstanding its manifest theoretical advantages. The choice of the mode of distribution is, indeed, a mere matter of economy, and the appreciation of the importance of the various conditions able to determine the selection must always constitute one of the most delicate parts of an engineer's duties. One of the most mischievous errors of the late General Board of Health consisted precisely in the absolute manner in which it compelled the adoption of this constant delivery at high pressure, under every possible condition.

272. The great irregularity which takes place in the consumption of water during the various hours of the day renders it necessary to use pipes of larger dimensions for the house services, upon the constant delivery, than would be required upon the intermittent one ; for, as the supply is taken directly from the service pipes in the former case without the interposition of any cistern or regulating storage vessel, those services must be large enough to allow the water to be drawn off very rapidly. The observations made by Mr. Martin of Wolverhampton upon the rate of consumption during the different hours of the day, may throw some light upon this subject, and they are therefore subjoined. He stated, in the Appendix ii. p. 67, of the (very equivocal) Report of the Board of Health on the Water Supply of the Metropolis, that the consumption varied as follows :

Time.	Per centage of gross consumption.	Time required to deliver total consumption at this rate.
Between 6 and 7 A.M.	3·735	26·77 hours.
„ 7 „ 8 „	5·209	19·19 „
„ 8 „ 9 „	6·192	16·14 „
„ 9 „ 10 „	6·438	15·53 „
„ 10 „ 11 „	7·076	14·13 „
„ 11 „ 12 „	7·764	12·88 „
„ 12 „ 1 P.M.	5·995	16·68 „
„ 1 „ 2 „	5·946	16·82 „
„ 2 „ 3 „	6·388	15·64 „
„ 3 „ 4 „	7·862	12·72 „
„ 4 „ 5 „	5·209	19·19 „
„ 5 „ 6 „	6·290	15·90 „
„ 6 „ 7 „	3·685	27·13 „
„ 7 „ 8 „	5·012	20·00 „
„ 8 „ 9 „	3·047	32·81 „
„ 9 „ 6 A.M.	14·152	68·26 „

273. Thence it would appear that the maximum

demand upon the mains occurred between the hours of 10 and 12 in the forenoon, and between 2 and 4 in the afternoon; but these conclusions can only be taken to be rigorously correct for the town particularly observed, and they may be, even in that town itself, materially influenced by the atmospheric conditions of the period when the observations are made. One thing is, however, proved by Mr. Martin's analysis, viz., that about  $\frac{3}{4}$  of the total supply is, upon the constant delivery, drawn off between the hours of 8 in the morning and 8 in the evening; and that on many occasions as much as  $\frac{1}{10}$  of the total quantity may be withdrawn in one hour. Mr. Hawksley's principle of assuming that it is necessary to make the pipes big enough to discharge  $\frac{1}{4}$  of the whole quantity in one hour, must therefore be considered to be justified by a due regard to the eventual requirements of a town which is likely to increase.

274. The following statistics of the consumption of water for the ordinary purposes of life may be here stated, as they will furnish the elements of calculating the dimensions of house services. Thus—

A bath requires on the average, each	Gallons.
time it is used . . . . .	75
A horse requires per day, about . . . .	16·5
A two-wheeled private carriage, per day	8·8
A four-wheeled ditto ditto . . . . .	16·5
Each individual in a house . . . . .	4·4 to 8·0
Every yard superficial of garden ground	0·33
Ditto, ditto, of roadway, per service	0·22

275. Before closing this section it may be as well to advert to the various descriptions of pipes used for the distribution of water, to their effects upon the quality

of the supply, and to the rules usually adopted for calculating their dimensions. These descriptions may be briefly stated to consist of cast-iron, wrought-iron (whether galvanised or not), and lead; and each of them gives rise to a special class of phenomena. Thus: cast-iron pipes, which are most commonly adopted, are preferred on account of their original strength and rigidity, of the facility with which they can be adapted to any change of direction in the line of pipes, and of their durability. Some waters, however, appear, as was before observed, § 192, to exercise a remarkable influence in developing the oxidation of cast-iron, and in producing tubercles which diminish the sectional area of the water-way, and render necessary frequent examination and cleansing of the pipes. Notwithstanding the discussions which have taken place on this subject, it is still involved in great obscurity; and the opinions expressed by M. Payen, in 1837, seem still to represent the most satisfactory known theory as to the mode under which the oxidation takes place. From a note by that eminent chemist, inserted in the "*Annales des Ponts et Chaussées*," of 1837, it would appear that the slightly alkaline, aërated, waters are those which are the most likely to produce the effect above mentioned. The oxidation takes place more readily upon grey cast-iron than upon whiter metal; and the experiments of both English and French engineers would appear to show that if cast-iron pipes be coated internally with a solution of hydraulic lime, or with linseed oil containing litharge, the formation of the tubercles will be retarded. Chloride of sodium, when present in the water, even in small quantities, exercises great influence in facilitating the development of such tubercles.

276. In some of the continental towns especially,



wrought-iron pipes have of late years been introduced for the distribution of water, instead of cast-iron, the inner surfaces of the pipes being galvanised, and the outer surfaces protected by a coating of asphalte. Notwithstanding the favour with which this system has been received, it would, however, appear that there are very serious practical objections to the use of the wrought-iron pipes; because a subsidence of the ground above or beneath them, might compress the pipes, and thus diminish their available sectional area, without producing at the same time any external indication by means of which it would be possible to identify the precise position of the interference with the flow. The very elasticity of these wrought-iron pipes is, indeed, a practical evil; for, under the circumstances above supposed, cast-iron pipes would either not yield to the superincumbent weight, or if that weight exceeded certain limits they would break, and thus by the leakage which would take place they would at once call attention to the defect. Wrought-iron service pipes are, however, often used successfully.

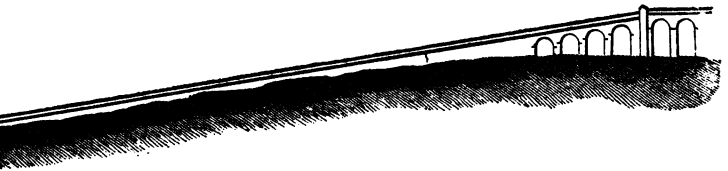
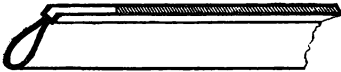
277. Lead pipes are those which are the most frequently used for house services; and they may be obtained by the process technically known as "drawing," when the diameters do not exceed three or four inches, beyond which dimensions they are only made by soldering the joint, or by casting. In the latter case the lengths of each particular pipe can hardly exceed ten feet, and under such circumstances the number of joints which would be required becomes a serious objection to their use. It was, indeed, on account of their being practically confined to the use of lead pipes that the Roman engineers so rarely adopted reversed siphons upon the lines of their aqueducts; and the difficulties they must have encountered in the

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To face page 245.

*Section of Pipes, Cement joint.*



**ACROSS THE VALLEY OF SONGIEU.**

**FRANCE.**

BUTTERNORTH & HEATH SC.

execution of the great work of this description, near Lyons, is sufficient to explain their preference for large bridges, even whilst it proves that the great principles of hydraulics were perfectly well known to them. At the present day, however, as was before stated, lead pipes are those most frequently used for house services; and they are found to be the most convenient, though perhaps not the most economical, on account of the ease with which they can be made to bend in any direction. It is important to mention here that lead is exposed to be acted upon by certain waters, and that its action when thus affected is far more prejudicial than is the action of iron similarly affected. The precise conditions of the action and reaction of water and lead are not very satisfactorily explained; but it would appear that the waters which are able to affect iron in the most decided manner are also those which are able to affect lead. Some of the soft waters, as they are called, or those destitute of the bicarbonate of lime, appear to act with the greatest energy on lead; and when this is the case the use of that metal for service pipes, or for cisterns must be carefully avoided. (See also § 101 Vol. I.)

278. The formula for ascertaining the thickness to be given to a cylindrical pipe exposed to a certain internal pressure is usually given as follows:  $x = \frac{p r}{c - r}$  in which  $p$ . = the pressure per square inch;  $r$  = the radius of the interior diameter; and  $c$  = the cohesive strength of the metal per square inch. In practice, however, the dimensions ascertained by the application of the formula are sometimes neglected, and especially in the cases of pipes of small diameter the thickness is made greater than theoretically it would be necessary to do, on account of the difficulty there would be in

obtaining sound castings with metal of the required thickness. It is customary also to strengthen pipes of more than 3 inches in diameter, by placing two belts  $3\frac{1}{2}$  inches wide, and  $\frac{1}{2}$  inch projection, in their length. Mr. Hawksley adopts, for the purpose of calculating the thickness of cast-iron pipes, a very simple empirical formula, which is sufficient to meet any ordinary contingency. He makes the thickness =  $0.18 \sqrt{d}$ , or in other words, he makes it about equal to  $\frac{1}{2}$  of the square root of the diameter. The following table contains the dimensions and the weights usually given in commerce to cast-iron pipes used for the purposes of the water supply of towns.

TABLE No.

Internal diameter of pipe.	No. of belts per pipe.	Length over joint.	Net length in work.	Weight per pipe.	Thickness of barrel.
In.		ft. in.	ft. in.	cwts. qrs. lbs.	in.
$1\frac{1}{2}$	none	4 9	4 6	0 1 0	0.288
2	"	6 4	6 0	0 1 21	0.3
$2\frac{1}{2}$	"	6 4	6 0	0 2 5	0.313
3	"	9 4	9 0	0 3 24	0.325
4	two belts	"	"	1 1 12	0.35
5	"	"	"	1 3 6	0.375
6	"	9 6	"	2 1 4	0.4
7	"	"	"	2 3 8	0.425
8	"	"	"	3 1 15	0.45
9	"	"	"	4 0 2	0.475
10	"	"	"	4 2 21	0.5
11	"	"	"	5 0 17	0.525
12	"	"	"	6 1 0	0.55
13	"	"	"	6 3 14	0.575
14	"	9 8	"	7 2 20	0.593
15	"	"	"	8 1 13	0.612

279. Mr. Jardine of Edinburgh found that a lead pipe  $1\frac{1}{2}$  inch in diameter, and  $\frac{1}{2}$  of an inch in thickness, resisted a head of water equal to 1000 feet, but that it

burst under a head of 1200 feet; and that a pipe 2 inches in diameter, of the same thickness, resisted a head of 860 feet, but burst under a head of 1000 feet. Belidor states that a large pipe of lead, 13 inches in diameter and  $1\frac{3}{8}$  thick, will resist a pressure of three atmospheres; and he mentions that the pipes in the Gardens of Versailles are 2 feet  $1\frac{3}{4}$  inches in diameter, and  $1\frac{3}{8}$  inch thick; these are about the largest lead pipes in existence. The usual thickness and weights of the lead pipes to be met with in commerce are as follows:—

	in.	in.	in.	in.	in.	in.	in.	in.
Thickness . .	1	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2
Weight per foot	4·85	5·34	5·81	6·3	6·79	7·27	7·76	8·73

280. It may be interesting to add that the ordinary charge for a water supply in England is about 5 per cent. upon the rental of the house, and that the following trades give rise to the application of special rates: such as manufacturers, tanners, fellmongers, hair-washers, glue-makers, curriers, dyers, hatters, brewers, distillers, inns, bath-houses, and steam-engines.


Whilst these pages were passing through the press, a very interesting account of the operations of the French engineers, who have lately been employed in sinking some Artesian wells in Algeria, has been published by General Desvaux, in the fifth number of the "Annales des Mines" for 1858, to which it may be the more necessary to call attention, because our own

fellow-countrymen have certainly been either less bold or less successful in their attempts to execute similar works than our neighbours have been. In all probability the course adopted by the French with such success, in forming wells in the heart of the great Desert of Sahara, might be followed with equal advantage in some parts of the Cape Colony, or in the great Stony Desert of India; perhaps even Australia itself might advantageously admit of the execution of wells in some of its now barren parts. At any rate, the influence of the wells recently formed in the Sahara upon the development of the civilisation of the interior of the mysterious continent of Africa, must be sufficiently important to justify a lengthened notice of the conditions of their execution.

The Desert of Sahara itself, appears to have, at no very remote geological distance of time, constituted the bed of an inland sea, analogous to the Mediterranean of the existing epoch, which was bounded, towards the north and north-west by the high lands now constituting the range of the Atlas. The strata of these lands actually dip under and form a continuous basin beneath the horizontal beds of the former deposits of the sea, and as some of those beds are sufficiently impermeable to prevent the waters, flowing from the present hills and entering the more absorbent strata, from rising to the surface, the waters so entering the underlying strata exist under the ordinary conditions of Artesian springs. Whenever, therefore, the upper impermeable strata are passed through, and the permeable water-bearing ones beneath them are reached, the water rises to a height regulated of course by the ordinary laws of Artesian springs, and with an abundance dependent upon the original

supply, and the demand made upon it. And here it may be as well to remark, that the results said to have been obtained, must still be regarded with some amount of suspicion; for it is far from being proved that they will remain such as they are, either throughout the year, or in any season when a greater number of similar wells are formed. Wherever the water has, however, been brought to the surface, it has been at once converted for irrigation or for personal use by the wandering tribes of the Desert, who are thus insensibly won from their nomadic state to the more peaceful life of the fixed cultivator.

Up to the end of 1857 no less than fifteen Artesian borings had been commenced, under the directions of the officers of the engineering corps of the French army of Algeria, in that part of the Desert comprised within the French dominions; and eleven of these wells had actually yielded copious supplies of water, whilst the remaining four borings were being continued with a fair prospect of success, in the cases of two at least out of the four. From the returns given by General Desvaux, it would appear that the total quantity of water thus poured upon the surface of the Desert, which only required this stimulus to become of unexampled fertility, has not been less than 4030 gallons per minute; and that one of the wells alone yielded as much as 946 gallons per minute, or above 1,400,000 gallons per day, which is nearly half as much again as the yield of the celebrated Artesian well of Grenelle. The following table, extracted from Gen. Desvaux's notice, and turned into English notation, will, however, give the most correct idea of the nature of the works thus executed, and of the results said to have been attained by them:—





Name of boring.	Yield, gallons per minute.	Temp. Fahr.	Depth of well.
Tamerna . . . .	882.2	69.8	196 ft. 6in.
Temacin . . . .	7.7	69.8	277 „ 9 „
Tamel'hat . . . .	26.4	71.6	191 „ 10 „
Side Rached . . . .	946.0	75.2	177 „ 2 „
Oum Thiour . . . .	39.6	69.8	343 „ 5 „
Chegga . . . . .	19.8	72.5	131 „ 3 „
El Visour . . . . .	733.92	77.0	162 „ 10 „
Sidi Sliman . . . .	880.0	77.0	245 „ 10 „
Bram . . . . .	440.0	75.2	157 „ 6 „
Oum Thiour, 2nd well	33.0	77.9	261 „ 9 „
Metkaonak . . . .	21.34	73.76	385 „ 5 „

There are some apparent anomalies in this table, which may perhaps confirm the doubts already expressed with respect to the probable permanence of the supply thus secured. For instance, the distance of the principal water-bearing stratum from the surface would seem to range between 150 and 200 feet; and if it should happen not to be met with in any particular place, the actual yield of the well is not likely to be of much importance. But the singular varieties stated to exist in the temperatures of the well waters, which rise to the surface, lead to the inference that the water-bearing stratum is not situated at such a depth as to protect it from the action of external disturbing causes; and therefore they also lead to the belief that those causes may be able to affect the regularity of the supply. A series of returns, carried over many years, is in fact required before any authentic opinion can be formed as to the real value of these interesting illustrations of the art of well-sinking; an art which seems, by the way, to

have been originally practised by the ancient Egyptians, and to have been applied by them to precisely the same purpose as it has lately been applied by the French, viz., the creation of halting stations in the dreary wastes of the Deserts. The number of rivers, and the quantity of water known to be absorbed by the Sahara, may diminish the probability of the importance of the disturbing causes above alluded to; but until a series of observations upon the permanence of the yield shall have been made, some doubts must exist on the subject. Before closing this note, it would be desirable to call attention to the fact that the range of the Atlas is more likely to furnish a permanent supply to the streams feeding the underground springs of Northern Africa, than are the mountains of either South Africa or of Australia; because the former are sufficiently lofty to rise into the regions of perpetual snow, whilst the latter are uncovered in the summer months. Nevertheless, the effects of droughts in both those regions are so fearful, that it would be important at least to examine whether there were, or were not, any probability of discovering even a partial remedy to them.

## CHAPTER IV.



### TOWN DRAINAGE.

281. THE subject of town drainage is one which is of such manifest importance to any highly-civilised community that the discussion of the best and most efficient system to be adopted in order to effect that object has at all times occupied the attention of legislators and engineers. The great Jewish lawgiver prescribed numerous precautions to secure the removal of the various offensive matters, and the ordinary drainage of the camp of his followers during their sojourn in the Wilderness; in the ruins of Babylon and Nimroud distinct traces of a system of drainage have been discovered; the great sewers of Rome, and of the Etrurian cities have long been the objects of admiration of antiquarians and engineers; later still we find our own Henry VIII. promulgating a code of laws upon the subject of sewers and drains; and within the present century the whole question has been studied with a degree of attention, almost of passion, far superior to that hitherto bestowed upon it. Unfortunately, however, the fashionable empiricism of the day has been allowed to play its most fantastic tricks in this matter; and it is, therefore, the more necessary to call attention to the real philosophy of town drainage. For the purpose of discussion it may, then, be considered that there are two branches of the subject, sufficiently distinguishable from one another for the purposes of

classification, and which may be, and often are, treated in practice upon very different principles. These branches, or sub-divisions, are—1st. The consideration of the means of removing the surface, or what may properly be called the drainage, waters; and, 2nd. The consideration of the means of removing all the foul house waters, and the excrementitious matters of a town population, in such wise as to ensure their effectual discharge without producing any annoyance, either to the inhabitants of the town under consideration, or to the proprietors of land situated below the point of outfall. At the same time, it is desirable that whatever fertilising properties may be retained in the *sewerage*, as the waters flowing from the house drainage are now commonly called, should be converted to use, if that object can be accomplished with due regard to economy. These sub-divisions, however, are but arbitrary; because when a large, and highly civilised, community establishes itself at any particular place, it frequently becomes difficult to define where the one of the sub-divisions begins and the other ends—especially as the existing municipal regulations of the countries of Western Europe complicate the question in an infinite number of ways. In fact, cities grow, without much apparent reason for the particular manner in which the increase of their populations affects the plan of their distribution; and it is very rarely that it is possible to predicate, or to provide for, the wants of the continually increasing flood of incomers. The difficulty of thus foreseeing the wants of future generations is, moreover, increased by the fact, that not only may the internal distribution of the towns alter, but also because, from time to time, changes are introduced (even into national habits, the most pertinacious of all) which defy any previous calculations. Perhaps

it is for these reasons that we find that both the systematic neglect of "red tape" in the department of public works of our own country, and the precisely opposite defects of our neighbour and rival, France, have failed to elucidate many of the obscure points connected with the subject now before us, and have equally proved to be sources of difficulty in the adaptation of modern refinements and improvements. After all, the common sense of engineering works is to deal with difficulties as they practically arise, without attempting either to establish any absolute theories, or to lay down any absolute laws.

282. Within a very recent period the sewerage of towns, as we now understand the phrase, can hardly be said to have been effected in any systematic manner; for the domestic arrangements of former generations were not such as to render it necessary to make special provisions for the removal of house drainage or of house refuse, by means of water. It was not, indeed, until the recent extension of the system of private water supply, and the general introduction of water-closets, both of which improvements in the details of daily life may be considered to date from the present century, that the want of an extended system of street and of house sewers made itself felt. Originally sewers were, as their name implies, the channels through which the land waters penned back by the tides, were at certain periods discharged through the banks, or sea-weirs, thrown up to prevent "the raging waters of the tides from overflowing the land;" and it is to be remarked that until within a very few years the word "sewer" was commonly written and pronounced "shore." The enormous quantities of water, however, supplied to modern houses have rendered it necessary to provide special means for the removal of such of them as had

discharged their functions in domestic economy; and thus eventually the relative proportions of land and of house drainage in towns have become entirely reversed. In fact, the land drainage, in such cases, is irregular in its character, and at times it ceases entirely to supply anything at the outfall; whilst the house drainage is permanent in its action, and yields nearly the same quantities in dry as in wet seasons—in summer as in winter; indeed, if any remark can be made on this subject, it would be that the house drainage is most likely to be copious when the land drainage entirely ceases to act upon the outlets. The ancient legislation upon the subject of sewerage was based upon the conditions of the preponderating importance of land drainage; and according to it, the discharge of foul house waters into a regular sewer was strictly forbidden, and punished very severely when discovered. Even so late as 1830, the prohibition against connecting house and street sewers was rigorously enforced in parts of London; and even at the present day, in Paris, it is only by tolerance that the surplus waters of the cesspools are allowed to overflow into the public sewers. But the advantages of the modern system of carrying off house refuse, by means of the waste waters of the houses themselves, are so great, that it is impossible long to resist the extension of the modern system; and, as sooner or later the sewerage and drainage of every large town must be carried out in a manner analogous to that lately adopted in our own Metropolis, it becomes important, firstly, to ascertain the laws which regulate the flow of water towards the town drains; and, secondly, to discuss the best methods of disposing of the contents of the latter, so as not to create a public nuisance.

288. Some modern writers upon the branch of

hydraulic engineering immediately before us have affected to resume the principles which should guide our practice in the matter, by saying in an epigrammatic form, that "all the rainfall is due to the rivers, and all the sewerage (or sewage, as they are pleased to call the house refuse) to the land." This is but a paradox, and like all paradoxes it contains a germ of truth; but if it be, as no doubt it is, desirable that the bulk of the rainfall of any particular place should be poured into its natural water-courses, and if it be desirable that none of the fertilising properties of house sewerage should be lost, there still remains the great question,—How is all this to be effected with due regard to economy? The practical result of any attempt to separate the two systems of sewerage would be to render inevitable the construction of two systems of drains; and though unquestionably there may exist some circumstances which may render it doubtful whether the concentration of the two descriptions of waste water in the same discharging drains be, or be not, desirable, it must be evident to every unprejudiced observer that no inflexible rule can exist in such cases. In fact, the course which might be advisable in one case may be highly objectionable in another, on account of the differences in the nature of the soil on which the town is built, of its configuration, of the character of the outfall, and of the character of the country around the town and around the outfall itself. Every case must therefore be dealt with on its own merits, and every attempt to lay down inflexible laws on the subject must be regarded as sheer empiricism.

284. As we have seen, the conditions to be observed in designing a perfect system of town drainage, are, 1°, that the whole of the surface and land waters should be removed; and, 2°, that the house refuse should be

carried away effectually and inoffensively. The attainment of the latter condition will depend upon the greater or the lesser abundance with which the water supply of a town is effected ; and thence it may almost be inferred that unless a good supply of water should exist, it would be inexpedient to attempt to introduce a system of house sewerage. As to the quantities of the land, and house waters, they must depend, in the first place, upon the rain-fall, and the other natural hydrographical peculiarities of the town, that is to say, upon the springs or watercourses it may contain ; and, in the second place, upon the number of inhabitants per house, and the maximum rate of consumption of water. In England, for instance, there are rarely more than six inhabitants per house ; whilst in France and in Scotland that number will at times reach forty, or even fifty. A moderate supply of water may be reckoned to require about from 20 to 40 gallons per head, per day ; and of this quantity about  $\frac{4}{5}$  will generally find its way into the sewers. Those channels, if they should be designed to carry off all the waters from the town under consideration, must be of sufficient capacity to discharge a volume of water calculated upon the above data ; together with any storm waters which are likely to flow into the channels. It has been observed that the greatest flow of house waters, in the sewers themselves, takes place between the hours of 11 and 1 ; and that in each of those hours the average flow is about  $\frac{1}{8}$  of that of the whole day ; though as Mr. Phillips appeared to be seeking, on the occasion of his giving the evidence from which the above rule was deduced, to influence the opinions of those whom he was addressing in favour of small drains, it is advisable to adhere to the more generally received opinion that it is preferable to reckon upon



carrying off, in each of the hours of greatest flow, at least  $\frac{1}{6}$  of the total quantity of the house sewerage.

285. The quantity of storm or of land waters to be carried off by a system of sewers, is even a more important element than the quantity of house water, in the calculations to be made in such cases; and whatever may be the precise amount assumed to be likely to find its way into the sewers, the latter must be made of such dimensions as to allow of its easy discharge simultaneously with that of the greatest flow of house sewerage. The rain-fall of the different parts of any large country, as is well known, varies in a very marked manner, on account of the atmospheric currents to which it may be exposed, and it is therefore necessary, before attempting to settle the dimensions of a system of sewers, to ascertain the maximum quantity they may be thus called upon to discharge; and as the sewers ought to carry off any ordinary floods, or storms, it follows that the observations on which such calculations are based, must extend over a very long period. Now, it is generally admitted by meteorologists that, although torrential rains occur with the greatest frequency in countries situated near the tropics, countries situated in higher latitudes are also occasionally exposed to their action. Thus, at Rome, where the average annual rain-fall is about 2 feet 8 inches, showers of 17 hours' duration, and yielding 5 inches of rain, have been observed; whilst at Marseilles, in a shower of 14 hours' duration, no less than 13 inches of rain have fallen, and at Arles, which is situated rather more inland than Marseilles, as much as eight inches have fallen in 12 hours. The greatest rain-fall recorded as having taken place at Southampton is about 2 inches in 10 hours; but in London, storms have occurred which have yielded as much as 4 inches

of rain in 2 hours, or 2 inches per hour. Unquestionably the latter observation must have been influenced by some very exceptional phenomenon, perhaps by something in the nature of a water-spout; but it appears from numerous other observations in England, that storms of equal violence with that recorded as having occurred at Southampton, are of sufficiently frequent occurrence to justify the assertion of the rule that, "when sewers are constructed to carry off storm waters in addition to the house waters of a district, they must be made of such capacity as to discharge a proportion of a 4-inch rain-fall in 24 hours, varying with the character of the district."

286. The variation thus alluded to depends upon the relation between the quantities of water falling upon a given area, and the quantity flowing off the same area, and this relation will, in its turn, depend greatly upon whether the district under consideration be urban or rural; and in the former case, upon the configuration of the surface, and the degree of permeability of the soil. It is usually calculated that in open country districts, where the soil is of a loose, permeable texture, only about  $\frac{1}{3}$  of the rainfall finds its way directly into the superficial water-courses; whilst in ordinary country towns about  $\frac{1}{3}$  of that quantity are estimated to flow at once into the sewers; and in larger towns, where the drainage is generally speaking most effectually carried into execution, and where the majority of the streets are paved, it is safer to calculate upon the basis that  $\frac{3}{4}$  of the total rain-fall will immediately find their way to the sewers. The results which would be arrived at upon these calculations are, it must be observed, far in excess of those which would follow from the application of the laws laid down by the referees of the Metropolitan Board of Works upon the

great drainage scheme ; for the referees seem to have considered that it would be sufficient to provide sewers able to actually carry off, in six hours, about  $\frac{1}{4}$  of an inch rainfall, in addition to the maximum house flow ; but they calculated upon the excess of the rain-fall, beyond this quantity, passing at once into the Thames through a series of storm overflows.

287. A point of equal importance with that of the sizes of the arterial sewers of a town is the one connected with the outfall and the mode of disposing of the sewerage when brought there. Hitherto the public authorities charged with the execution of this description of works have contented themselves with pouring the waters collected by the sewers into the natural outfalls or drainage channels of their respective districts ; but the constantly deteriorating quality of town sewerage, so far as it is able to affect public health, and its increasing value as a means of manuring land, have led to much discussion and to many partially successful attempts to obviate on one hand the nuisance, and on the other to appropriate the fertilising powers said to be now wasted. Two methods of effecting these objects have been brought of late prominently before the public : viz. the method of distributing the sewerage over agricultural lands by a system of irrigation, and the method of precipitating in a solid form the matters in suspension in the sewerage ; and as the partisans of the respective systems have succeeded in diffusing some very incorrect opinions as to their merits, it may be advisable to dwell a little upon the subject.

288. In the method of disposing of town sewerage by a system of irrigation it is essential that some means should be adopted to exclude storm waters from those supplied by the house drains, because the regularity in the composition of the irrigation waters is one

of the most important conditions of their permanently successful action. Unless, therefore, the sewerage of the town supposed to be thus treated be entirely separated from the land drainage, by the execution of an entirely distinct series of channels, there must be provided some description of storm overflow, and in such a case it would be impossible to say that the nuisance arising from the discharge of the sewerage into the water courses had been obviated. This is far from being a hypothetical inconvenience, for in the case of the town of Rugby actions at law, on account of the damage done by storm waters overflowing from the sewerage outfall constructed for the purpose of a distribution of the town refuse by irrigation, have been maintained, and the town has been compelled to erect a series of filter beds in order to mitigate the evil thus created. But even should there be no reason to fear the contamination of the water-courses in consequence of occasional overflows, the irregularity which would prevail in the quantity and quality of the sewerage to be pumped must always complicate the question of its distribution in this manner, for the delivery pipes and the engine power must be adapted to the maximum duty they may have to perform, rather than to the average duty. It is to be observed also that a system of irrigation, whether by means of sewerage or of any other waters, can only be applied upon grass lands with any economical advantage, in our latitudes at least; and that one of the essential conditions for its success is that the land upon which it is applied should be adapted either by its configuration, by its natural porosity, or by the execution of a complete subsidiary system of thorough drainage for the rapid and complete removal of the waters furnished by the irrigation. Moreover the land upon which the sewerage waters

are thus proposed to be poured, should be situated at a lower level than the outfall furnishing those waters; so that unless great natural facilities should exist, the application of this irrigation system must be accompanied, as in the case of Rugby before mentioned, by a costly series of pumping and distributing works. In this particular instance of Rugby the waters are pumped from the low-lying outfall of the town upon some very porous higher land, principally laid down in grass, and are distributed over it through a series of cast iron mains, stand pipes, and flexible hose; but although the works have been designed, and are conducted, with great practical skill, it is more than questionable whether the results obtained by this system of irrigation are superior to those which would be obtained by an irrigation with ordinary river water; and it is tolerably certain that the benefit gained is not equivalent to the outlay and the working expense the system involves. The spirited proprietor of the Rugby Works pays a rent to the town for the sewerage waters; in justice he ought to be paid for receiving them, for were he not a wealthy man the operation itself would be ruinous.

289. A great deal of importance was attached by the authors of the various Reports, issued some years since by the late General Board of Health, to the results obtained at Edinburgh from a partial application of a system of sewerage irrigation, and to the assumed confirmation of the theories they had endeavoured to diffuse upon the merits of such a mode of disposing of town refuse, by the results of the irrigation effected in the immediate neighbourhood of Milan. But it must be observed, with respect to the irrigation of the neighbourhood of Edinburgh, that, firstly, the operation was effected by merely allowing

the sewerage waters to flow by gravitation over a district composed of a light open sand, through which the water easily permeated, without any artificial drainage; and that, secondly, the habits of the dwellers in the particular part of Edinburgh where this experiment was tried were not similar to those of the majority of English cities. In fact, the waters distributed in this particular case were rather drainage waters than sewerage waters, as the term is usually applied; and they were neither obtained in the quantity, nor were they of the quality, which would have to be dealt with in ordinary English towns, where copious water supplies and a complete system of impermeable sewers now exist. The very nature of the ground, moreover, upon which the Edinburgh sewerage is poured tends to render the operation less objectionable than it would be in ordinary cases; but even upon it the gradual accumulation of decomposing and fertilising matter is productive of very serious annoyance, which would become intolerable in any less exposed situation than the one occupied by Edinburgh upon the shores of the Firth of Forth. No doubt the barren sands of this particular place have been rendered extremely valuable by the application of the sewerage waters; but unless such land should exist in the immediate vicinity of a town, and unless there should also exist very efficient natural means of ventilation, it is more than questionable whether the system, which has answered so well in this case, would be likely to succeed as well elsewhere. Certain it is that the system applicable to the sandy fields between Edinburgh and Leith would not be applicable to the clay lands round London, or round towns situated under similar geological conditions.

290. As to the irrigation of the country round Milan, it differs so essentially from the irrigation which

would be effected by the application of any English town sewerage, that it must always be a matter of surprise that our authorities should have cited it as furnishing anything like a parallel illustration of the theories they sought to establish. It is notorious, in fact, that the details of the ædility of Italian towns are so essentially different from those of our own country, that it is absurd to draw any common inference from conditions so dissimilar. No doubt the waters of the Navigho Grande, and of the other Milanese canals, take up considerable quantities of organic matters during their course through the town; but the relative proportions of the fertilising liquids and of the pure water in those canals, after leaving the town, are, from the habits of the Milanese and the municipal regulations enforced amongst them, only slightly different from those which might be discovered in the same canals before they received the drainage from the streets and houses. There is, in this case, a great quantity of water and a very small quantity of sewerage; whereas at the outfalls of the sewers of English towns the organic matters furnished by the houses are notably present in very great quantity. A comparison between the irrigation of the neighbourhood of Milan, and that which might be effected near any well-sewered English city is simply impossible; and it certainly would be more rational to compare the irrigation of such a district as that of the basin of the Itchen with the irrigation of the lower Milanese, than to attempt to draw from the latter any illustration of what could be effected at the outfalls of the sewerage of such towns as Manchester, Norwich, &c. An irrigation by means of ordinary river water, or at any rate by means of the tidal waters flowing in such creeks as the Counters Creek, on the banks of the Thames, would be quite as

advantageous as the irrigation carried on below Milan; and it is worthy of remark that, in the later days of the London Sewerage Irrigation Company, the pumps actually distributed in Fulham Fields the waters drawn from the tidal stream flowing in front of the works. It is curious, and perhaps the fact itself may have an extraneous importance, as it shows how utterly incompetent the parties who wrote the Reports of the late General Board of Health, to which reference is thus made, were to observe the facts before them, that the *Marcite* of Northern Italy, cited by them as proving the advantages of an irrigation by town sewerage, are precisely the meadows irrigated by springs which have never been susceptible of contamination by intermixture with the waters flowing either above or below the surface of any town district. The wonderful results obtained by the application of irrigation in the neighbourhood of Milan, therefore, prove that in warm climates water alone is an invaluable fertiliser; the same law prevails even in our own country, and it cannot be too often repeated that we, in England, are very far from deriving all the benefit of this description we ought to do from our rivers; but these facts prove nothing either for or against the system of irrigation by sewerage waters, and the application of such a system must depend upon many very complicated local considerations connected with the quality of the waters to be distributed, and the chemical nature and the physical configuration of the district to be operated upon.

291. Until within a very few years, the system adopted in Paris, the self-styled centre of European civilisation, for disposing of the faecal matters we in England cast with profligate waste into the ordinary water-courses of the country, was in fact an organised nuisance



of the foulest and most gigantic description. The night-carts, in fact, discharged their contents into a series of basins at Montfaucon, close to the barriers of Paris, on the north-east corner of the town; and there the said contents were allowed to desiccate by the simple action of the sun and wind, giving off, of course, during the operation miasmas of the most repulsive character. Some of the best quarters of Paris were within range of these miasmas, and some of the largest hospitals of the town were equally within their influence; and fearful indeed were the ravages of gangrene amongst the patients, when the wind set towards the hospitals from these huge collections of filth. At last the municipality of Paris has, however, been compelled to make a change in this matter; and it may be suspected that the daily extending application of the water-closet system has had much to do with the alteration. The system now adopted is to bring all the carts to a large covered building near La Villette, and there the more solid matters obtained from ordinary cess-pools are at once loaded into covered barges; whilst the more liquid matters are received into large reservoirs, to be thence pumped to an establishment situated at Bondy, at a considerable distance from Paris, where both the solid and the liquid matters are treated for the purpose of being converted into a manure, which is highly esteemed in France, and sold under the name of *poudrette*. This conversion into a manure is effected by a company, and it pays to the town of Paris no less a sum than £5400 per annum for the materials thus supplied to it; but it is not to be inferred from this fact that the inhabitants of Paris are gainers to the apparent extent indicated by the sum above quoted, for the householders are obliged not only to incur a very heavy outlay for the construction

of the cess-pools, but also to pay very heavily for their being opened and emptied. When, in addition to this, the expense to the town of pumping the sewerage matters to Bondy is taken into account, it must be reasonable to suppose that the ultimate cost of the French system of dealing with those matters is at least as costly as the one adopted in our own country. As to the nuisance, both in private houses and in the manufacture of the manure, there cannot be a shadow of a doubt as to the superiority of the system of removing house refuse by means of water; provided always that means are at the same time adopted for preventing the latter from becoming in themselves sources of nuisance, such as were formed at Croydon, Southampton, Hitchin, Sandgate, Epsom, &c. It is strange, however, and worthy of more than a passing remark, that the highly educated, but centralised body of Engineers who guide the proceedings of the municipality of Paris, were precisely the men who retained as long as they possibly could do so, the barbarous system of Montfaucon, with all its gigantic evils; whilst every real improvement in this important section of the duties of the ædility of towns has been introduced and carried into effect in our own country, where the profession of engineering is open to the whole world, and, until within a very short period, without any intervention on the part of the State.

292. The results of the pumping operations between La Vilette and Bondy would merit consideration from those of our municipal authorities who are likely to encounter similar difficulties; and at the precise period of the publication of this Treatise the attention of the Metropolitan Board of Works might be especially directed to them. The pipe between the extremities of the Paris works is about  $6\frac{1}{4}$  miles in length, and of

1 foot diameter, along which the liquid sewerage is forced by means of a steam engine working some force pumps, at the rate of about 131 cubic yards per hour. Very little difficulty arises in practice, from the character of the materials thus driven along the pipe, and the interposition of two coarse strainers in its length is found to be sufficient to guarantee it from becoming choked. A short account of the works thus referred to will be found in the "*Annales des Ponts et Chaussées*" for the year 1854.

293. The method of precipitating the fertilising properties of the town sewerage in a solid form has been applied, in our own country, in several modes which may summarily be described by saying that they consist either in a mere mechanical separation of the solid bodies in suspension by a kind of rude filtration in the style adopted at Ely, or in a rude precipitation of the suspended, and of some of the dissolved matters, in the style adopted at Leicester. The Ely system may be tolerated for a time in the case of a small town discharging its waters into a stream of considerable volume; but as even the most perfect filtration of sewerage waters must still allow the waters impregnated with the ammoniacal matters they contain to pass into the outfall, not only must such a filtration fail to arrest the most valuable ingredients of town sewerage, but it must also leave the waters in a state nearly as objectionable as that in which they were before being filtered. At Leicester, the operations of the Patent Manure Company were conducted upon a much bolder, and apparently upon a far more logical system, than in any other case, but the practical results of the experiment have been commercially disastrous in the extreme. The system adopted there was to lead the town sewerage into a series of basins where it was mixed with a quantity of the milk

of lime, and allowed gradually to deposit or to precipitate the matters that agent was able to separate; according to the dilution of the sewerage matters the waters remained a greater or lesser period in the depositing tanks, and from them it flowed apparently and practically clear into the water-courses of the district. It was originally supposed that the solid matters thrown down in this manner would constitute a valuable manure, and that its sale would cover the expense of the operation; unfortunately however, the manure thus obtained has so very small a commercial value that it is hardly worth removing, and no demand for it can be said to exist. In fact, the failure of the Leicester sewerage operations, *in a commercial point of view*, has been even more decided than that of the irrigation works at Rugby. There can be no doubt of the complete success of the Leicester system, so far as the purification of the water is concerned; but hitherto the operation has been very far indeed from being self-supporting.

294. Although so little success has hitherto attended the efforts of those who have attempted to convert town sewerage into a remunerative article of commerce, there can be no doubt of the moral obligation of all municipal bodies, or private parties, to intercept the passage of bodies likely to contaminate the natural water-courses of the district in which the outfall of their sewerage is situated. The fulfilment of this obligation is a mere matter of expense, and no consideration of this description ought to be allowed to stand in the way of the prevention, or the removal, of a great public nuisance; and it is to be observed that the evil arising from the discharge of sewerage into the streams or natural drainage outfalls of the country is one of a continually increasing magnitude. Not only indeed is

there a tendency on the part of modern civilised society to throw upon the sewers of towns duties or functions performed, even within a very recent period, by other means; but the importance of the water-courses as sources of water supply increases with the very demand for water occasioned by the same proceedings which tend in their turn to increase the quantity, whilst they deteriorate the quality, of the sewerage. In cases where the flow of the water is all in one direction there may be less immediate danger in discharging sewerage into the ordinary outfalls of the district, than there is when the removal of the refuse is opposed by artificial or natural impediments to the flow, as for instance by locks, wears, or by tidal action. But even in such cases, or in the more striking ones where the discharge of the sewerage takes place upon the sea shore, the evils arising from the partial retention of sewerage matters are so great that it becomes the duty of the English legislature especially to provide some more efficient method than now exists of compelling the municipal bodies entrusted with the management of the sewerage to fulfil their duties in this matter. One of the most serious mistakes of the leaders of the late General Board of Health consisted in fact in the urgency with which they recommended and enforced, as far as they possibly could, the adoption of the water-closet system without providing for the disposal of the refuse thus removed.

295. The nature of the soil of a town (referred to in § 291. as being likely to affect the details of a system of sewerage) may influence the dimensions, and the materials to be employed, according as it may facilitate or impede the escape of land-waters or springs. Thus in many parts of London, and also in the neighbourhood of Southampton, there exist small elevations,

the surface strata of which consist of an impermeable brick earth, lying upon a stratum of gravel and sand, which in its turn, caps the stiff retentive blue clay of the English tertiary series. In many cases the upper stratum of brick earth is wanting, and the gravel forms the immediate surface stratum; whilst in others again, both the brick earth and gravel are wanting, and the blue clay is entirely exposed. Now, if in such a district as either of those named, a large area should be found presenting a section like that of Fig. 1, in



which the portion between B and C would represent the brick earth; the lightly-shaded part between A B and C D, the gravel; and the dark lower stratum, the blue clay; the drains of the respective portions on the longer slope towards C D E would require to be adapted to very variable conditions. Thus, the drains and sewers between B and C need only be made of such dimensions as should effectually suffice to remove the surface, and the house waters supplied by the district; but those to be formed between C and D, and still more decidedly those to be formed below D, must be able not only to discharge the waters poured in from the upper district, and their own sewerage, but also to discharge the waters which filter through the exposed surfaces of the gravel, and naturally discharge themselves in the greatest abundance near D. Near London the exposed surfaces of gravel are generally so small, that the water yielded by them does not require to be taken into account; for the dimensions usually

given to the sewers, in order to enable them to carry off storm-waters, are more than sufficient to relieve the strata traversed by these springs, which are necessarily characterised by a certain degree of regularity in their flow. At Southampton, however, the extent of the superficial gravel is, proportionally, much greater; and it is found in that town that, after a continuance of wet weather, the whole of the lower portions of the gravel become charged with water to such an extent as to inundate the basements situated below the level of the natural ground, unless in such places as possess sewers large enough to furnish a permanent outlet for the subterranean waters.

296. In some parts of Paris the same phenomena occur on a larger scale, and with greater irregularity than in the cases above cited. A considerable portion of Paris is, in fact, built upon a surface which originally constituted a marshy plain between the river and the hills of Belleville and Montmartre. The low lands of this district are composed of a calcareous formation, called geologically the lower fresh-water limestone, which allows water to infiltrate with great difficulty; whilst the hill sides are formed of the gypseous deposits with their associated marls, capped by a deep stratum of sand and permeable sandstone, or occasionally by the upper fresh-water limestone resting on these sands and sandstones. These sands occupy a considerable breadth of the country in the direction towards Belleville, and they consequently receive a copious supply of water during the rainy seasons. At the same time the various hills present steep escarpments, so that the storm-waters falling upon them can escape with great rapidity, giving rise to occasional floods of great violence. In order, therefore, to obviate any inconvenience from these circumstances, the inter-

cepting culvert, executed along the line of the greatest depression of the low lands, has been formed of much larger dimensions than the area it immediately drains would appear to require. In spite of this precaution, it is by no means a rare occurrence that the basements of the part of Paris, near the *égout de ceinture*, are flooded during the rainy season, or on the occasion of violent summer rains. It is worthy of remark, that the Cloaca Maxima of Rome was also designed, more for the purpose of relieving the subterranean waters of the low grounds between the seven hills, than for the discharge of the surface drainage.

297. If the geological structure of the soil of a town appear thus, in some cases, to increase the difficulties in the way of the execution of its sewerage, there may be other cases in which it would produce precisely opposite results, so far at least as the removal of surface waters is concerned. Thus in Weymouth, the portion of the town constituting the ancient borough of Melcombe Regis, is constructed upon a bed of shingle, which is in fact nothing more than a bar thrown across the mouth of the Wey. In order to remove the surface waters of this town, all that is required to be done is to form openings from the paved roads or courts into this shingle—absorbing wells in fact—and the waters immediately sink to the level of the sea. In some parts of Liverpool also, advantage is taken of the absorbent nature of the gravel to allow the surface waters to escape by filtering into it; for occasionally the lower portions of the drains were formerly executed with bricks laid dry, whilst they were only set in mortar in the upper portions. Absorbing wells have, indeed, been frequently used for the purpose of disposing of local drainage in gravelly and in fissured limestone districts; and an attempt was even made to get rid of



the foul waters of one of the Paris abattoirs by a well of that description; but as such absorbing wells must eventually contaminate all the ordinary wells deriving their supply from the water-bearing stratum thus communicated with, it seems to be almost imperative upon the guardians of the public health to prevent the execution of such wells, notwithstanding the private benefits they may occasionally confer.

298. The configuration of a district (under which term are comprised the general conditions of its division into subordinate districts of hill and dale) will also influence the details of the system of sewerage to be adopted, insomuch as it may affect the number, dimensions, inclinations, and directions of the main sewers. New and distinct outfalls may be required for the several portions; and as in many cases, in towns situated upon the banks of tidal rivers, one part may possess a constant discharge by gravitation, and the remainder may only have an intermittent, or even an exclusively artificial, outfall, it may be requisite even to treat the various portions of such towns in very different manners. The great scheme for the improvement of the London sewerage may be referred to as an illustration of the practice of the ablest engineers in such cases, and much useful information with respect to the principles of town drainage may be obtained from the various discussions which have taken place on the subject; and perhaps more information is to be obtained from these discussions than is usually the case, on account of the extraordinary amount of passion and jealousy exhibited during their progress. The following seem to be amongst the most important lessons to be derived from the investigation.

299. In towns presenting the configuration recently described, that is to say, having a considerable portion

of their area situated upon rising ground, and the remainder either upon the level of high tides, or below that line, it is advisable to adopt the course usually followed in draining important agricultural districts, or to form a large intercepting drain which should carry off the waters from the higher grounds, in a permanent manner, so as not to throw anything into the drains of the lower district; and then to deal with the waters of the lower districts, either by permitting an intermittent tidal discharge, or by raising them mechanically in a continuous manner. No doubt there would be economy in the introduction of an intermittent, or half tide discharge of the sewers, but such a system is objectionable, first, because it would render necessary the construction of sewers large enough to contain the waters ponded back between the periods of discharge; and secondly, because if a storm should occur during the period of the retention of the waters, the basements of the houses in the district would in all probability be inundated. Practically it would appear that it would be preferable in such cases to provide at once for the artificial relief of the drainage of the low-lying districts, and to design the pumping apparatus required for that purpose upon the supposition that it should be able to raise to the permanent natural outfall in a constant equable manner, the maximum quantity likely to find its way into the sewers. The conditions it is subsequently necessary to take into consideration in settling the dimensions of sewers, may be thus enumerated:—

1. The area of the district to be relieved.
2. Its population, both actual and prospective.
3. The amount of sewerage furnished by the district; and this, it is to be observed, is calculated, in London, at the average rate of from 5 to 7 cubic feet per head of the population, per day.

4. The rain-flow to be removed, calculated at the rate of  $\frac{1}{4}$ " in 24 hours in the higher, and of  $\frac{1}{16}$  of an inch in the lower districts.
5. The rain-flow and sewerage combined.
6. The accumulated amount of rain-flow and sewerage.
7. The length of the sewer, in portions, in order to accommodate its dimensions to the work required to be performed in such district.
8. The level of the invert of the sewer, its inclination and diameter, in so far as they are likely to affect the rate and conditions of the flow of the sewerage.

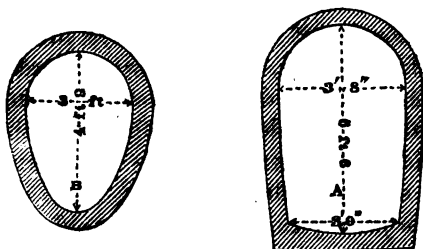
It may here be added that Mr. Hawkesley, (by far the best authority on the subject, practically and theoretically,) gives as a rule for calculating the diameter of sewers in town districts, when the number of acres to be drained =  $A$ , and the rate of inclination in feet per mile of the sewer, =  $n$ , were previously known, the formula  $3 \log. A + \log. n + 6.8 = \log.$  of diameter of the sewer in inches. The constant 6.8 may be increased if the inclination of the surface should naturally be slight.

300. It is essential to observe, in the construction of sewers designed to hold water during any definite part of the day, that they should be made of sufficient strength to resist the maximum hydrostatic pressure produced by the water flowing from the higher portions of their contributing area. As a general rule, however, sewers are more likely to fail by the pressure from without, than from the internal pressure; and it thence follows that the mode of executing the foundations, and the capabilities of the materials employed to resist a crushing weight, must be carefully examined. It is usually considered advisable to place the main sewers of a town about from 10 to 12 feet below the surface of the streets, and under these circumstances it is requi-

site to allow for the dead weight of the earth, and for the concussions which may be produced by any passing load. The usual thickness adopted for the main sewers of London, is either 18 or  $22\frac{1}{2}$  inches, and for the submains 9 inches, at the crown, according to the diameter, and to the distance from the surface; but naturally this dimension is regulated by the quality of the bricks or other materials used, and by the transverse section of the sewer.

301. The principles which should guide the decision as to the transverse section, are, primarily, that the smallest possible wet contour should be presented in proportion to the area of the water flowing at various periods in the sewer; and, secondarily, that the section should be such as can easily be examined and repaired. The ordinary London submain sewers fulfil these conditions in a very remarkable manner, and they may be thus described. Their heights, from invert to intrados, vary, according to the extent of the area, from 4 ft. 9 in. to 4 ft., 3 ft. 9 in., 3 ft. 6 in., and 3 ft. 3 in.; and the widths vary from 3 feet in the larger to 2 feet in the smaller sewers: the upper parts are semicircular, the inverts are portions of circles of 18 inches in diameter, and the sides are portions of curves tangential to the inverts and crowns. In such sewers, which, in fact, roughly approach the form of an egg placed on its major axis, the frictional surface, in proportion to the average hydraulic depth, is very small, and, on an emergency, it would be possible to send a workman down either of them, though of course it would be essential to take precautions against the effects of the foul air which might accumulate in them. The large main sewers of London are formed nearly upon the same principle, and of a similar section to the submains; but in Paris the engineers still adhere, as far

as possible, to a rectangular section. It may be as well here to state that the junctions of the submains



with the great arterial sewers are always made portions of circles on plan, and that the levels of the axes of the invert are kept on the same line.

302. A great deal of discussion has taken place of late with respect to the introduction of the glazed stoneware pipes, and, for a long time, it was even pretended by the late General Board of Health, that no other material ought to be employed, even for the submains of the metropolis. These pipes were designated, no doubt, with the intention of creating a popular prejudice in their favour, as "self-cleansing;" whilst the ordinary brick drains were as constantly called "sewers of deposit." Time and practical observation have fortunately dispelled much of the evil resulting from these exaggerations, and it is now generally admitted that, under the ordinary conditions which prevail in our English towns, pipe drains are preferable to brick ones, so long as the diameters do not exceed one foot in the clear; that between one foot and 18 inches diameter, local considerations of economy and of superincumbent pressure must decide the system to be adopted; and that above 1 foot 6 inches in diameter, there can be no hesitation in according the preference to ordinary brickwork, or to the use of invert of a

peculiar shape formed of fireclay, or of the blue Staffordshire ware. There is a question connected with the use of pipe-drains, which is still involved in obscurity, viz., whether or not the nonabsorbent quality of the ware of which they are made be an indispensable condition of their success? and this question was raised with some degree of acrimony when the Aylesford pipes were first introduced into the London market. The stoneware drain-pipes made at Lambeth, it is known, are formed from a mixture of the clays of Dorsetshire and Devonshire, with broken shreds, and occasionally with sand and flint; and this mixture burnt at a proper temperature, yields a very dense, semi-vitrified, nonabsorbent material. The Aylesford pipes, on the contrary, are made from a clay containing a considerable proportion of carbonate of lime, and they cannot, therefore, be burnt to the same degree as the ordinary stoneware; but still they are burnt at a temperature which admits of their being salt glazed. From this circumstance the Aylesford pipes are much more absorbent than the stoneware pipes, and serious objections were on that account made to the use of the former. The truth of the matter appears to be that if the sewerage waters should be likely to remain long in contact with the drain-pipes, it would be preferable to use the nonabsorbent material, rather than the more porous one; not only for the purpose of obviating any danger from the escape of the sewerage through the body of the pipe, but also because the stoneware pipes are less exposed to be acted upon than the Aylesford pipes would be, by the dilute acids, which are so frequently present in sewerage waters. If, however, there be a constant discharge, and a rapid fall in the drains, the Aylesford pipes would be preferable to the stoneware pipes, because they are less brittle, and less

exposed to distortion in the kiln. In fact, discretion is required in the selection of pipes, as in every other branch of engineering; for occasionally even economical considerations must be cast aside, as in the selection of drain-pipes, for some particular position, whilst in others it would be folly to allow other than economical considerations to influence the decision.

303. For house drains the experience of engineers appears to prove that there is danger in using a smaller diameter than 6 inches, when more than one water-closet communicates with the drain; and here again it is necessary to call attention to the mischief produced by the authorities of the late Board of Health, who originally compelled the use of 3-inch house drains—most of which have subsequently been removed. Wherever it is possible so to do, it is advisable to give pipe drains a fall of 1 in 48; but under extraordinary circumstances, and with a very good supply of water, a maximum inclination of 1 in 80 may be admitted for a 6-inch drain. It is to be observed, however, that these great inclinations are required, rather for the purpose of preventing the accumulation of deposit of a bulky and light nature, than of preventing the deposition of heavier matters; for a velocity of about  $2\frac{1}{2}$  to 3 feet per second will suffice to carry forward the matters ordinarily suspended in the waters of large sewers. Moreover, as the house drains fall into the sewers at a level which is only 1 foot above that of the axis of the invert (as a general rule), the rapid fall above described is required in order to protect the basements of houses from being flooded by any accidental accumulation of storm waters in the sewers.

304. One of the most important precautions to be observed in the execution of a system of house drainage is that means should be adopted to prevent the escape

of foul air from the drains into the houses. All the descending pipes leading to the drains must be carefully trapped; but as the foul air would force its way into the rooms, through almost any description of trap, unless an escape be provided for it without the house, it is equally essential to provide an outlet for the gases of the drains. One of the most satisfactory modes of effecting this object is to connect a closely fitting rain-water pipe, finishing at a level higher than any portion of the inhabited part of the house, with the drains. In positions wherein the sewers are exposed to be tide-locked, it is more than usually necessary to observe the precautions above alluded to with respect to their ventilation.

305. In addition to the remarks above made (§ 305.), on the transverse section to be given to a sewer, it may be added that the longitudinal fall must be at least such as to ensure a minimum velocity, in the water flowing in it, of 2 feet 6 inches per second upon the frictional surface. According, therefore, to the known laws of hydrodynamics, the larger the sewer, the less may be its inclination; but practically it is found advisable to limit the longitudinal inclination of the submain sewers to 1 in 240. If it should be necessary to adopt a slighter inclination than this, it would be necessary to construct a number of side entrances, and even to provide flushing gates, in order to remove any accumulation of the solid matters which find their way into the sewers: and that there is danger from this source must be evident, on reflection, from the fact that in the London sewers even, where the flow of water is so enormous, there is at least 1 ton of manure suspended in every 266 tons of water, according to the calculations of Mr. Wicksteed; and Mr. Austin said, in his evidence before the Commission on the Health of Towns, that



the proportion of solids to liquids in sewers varies from 1 in 96 to 1 in 36; and that from 1 to 66 or 1 in 80 is the smallest proportion consistent with an easy maintenance of the cleanliness of the sewers. Mr. Wicksteed, in one of his valuable Reports, laid down some practical rules on the subject of the inclination of sewers which perhaps it may be advisable to insert here, as the results obtained by a capable observer from a very extended practice. After stating that in his opinion no house drains should be made less than 6 inches in diameter, and that no combined back drains should ever be made less than 9 or 12 inches in diameter, he observed that a velocity of 180 feet per minute, or 3 feet per second, would suffice to remove the deposit of large sewers, but that a velocity of 220 feet per minute was required in pipe drains. He gave the following table of the diameters of circular sewers, with the velocities, and the gradients necessary to keep them clear:—

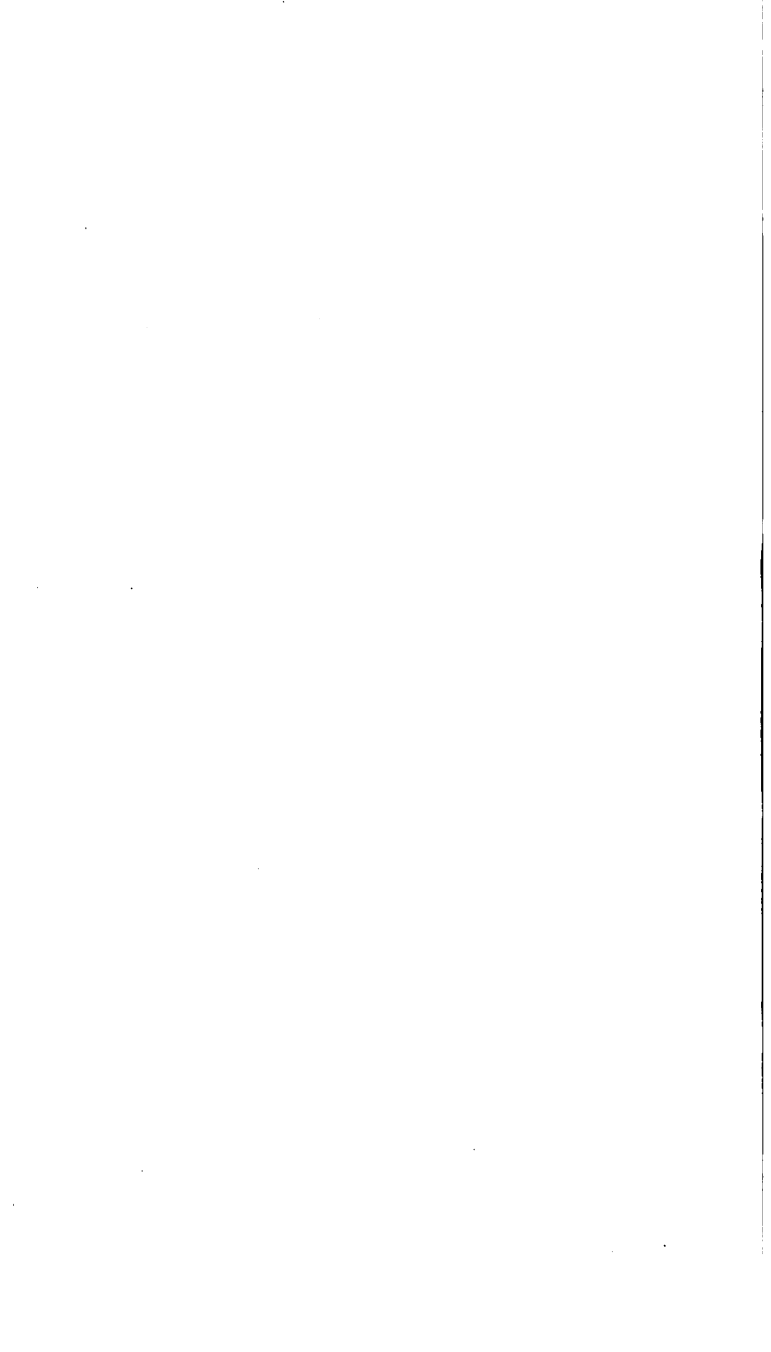
Diameter.	Velocity, feet per minute.	Gradient.
4 inches.	240 feet.	1 in 36
6     "	220     "	1     " 65
7     "	220     "	1     " 76
8     "	220     "	1     " 87
9     "	220     "	1     " 98
10    "	210     "	1     " 119
11    "	200     "	1     " 145
12    "	190     "	1     " 175
15    "	180     "	1     " 244
18    "	180     "	1     " 294
21    "	180     "	1     " 343
24    "	180     "	1     " 392
30    "	180     "	1     " 490
36    "	180     "	1     " 588
42    "	180     "	1     " 686
48    "	180     "	1     " 784
54    "	180     "	1     " 882

It will be observed that the velocities considered by Mr. Wicksteed to be desirable are greater than those admitted by other engineers; but the inconvenience produced by the stoppage of sewers is so great, that it certainly would be preferable to err upon the safe side and to adopt the greater inclinations.

306. In concluding this portion of the Rudiments of Hydraulic Engineering, it may be advisable to repeat what has been in fact already frequently mentioned in the text, viz. that there are no invariable or inflexible laws with respect to the application of the abstract theoretical principles upon which the science itself is founded. Local circumstances must always be taken seriously into consideration, and must be allowed their due weight, previously to deciding upon the details of any works for the purposes of drainage, irrigation, water supply, or sewerage. But after all, it will be necessary to refer constantly to the general scientific laws ascertained by the observations and experiments of engineers and philosophers; and these laws are, unfortunately, very different indeed from the crude fancies of the so-called sanitary reformers, who have lately presumed to throw doubts upon the observations of their predecessors, without being able themselves even to observe correctly. The best remedy to the evil produced by this official empiricism will be found in the study of the great masters of the science of hydraulics; and for this purpose the reader is referred to the list of the most esteemed authors on that science, which will be found at the end of this series of Rudimentary Treatises.

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